BACHELOR THESIS (ME 141502)

THE EFFECT OF DIESEL ENGINE 93 KW ON TURBOCHARGER PERFORMANCE AT VARIOUS SPEED AND LOAD

Muhammad Sidiq Prabowo
NRP 4212101021

Academic Supervisor:

1. Ir. Aguk Zuhdi Muhammad Fathallah, M.Eng, Ph.D
2. Dr. Benny Cahyono, ST, MT

DOUBLE DEGREE MARINE ENGINEERING (DD ME) PROGRAM
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Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember (ITS)
Hochschule Wismar, University of Applied Science
Surabaya
2017

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SKRIPSI (ME 141502)

EFEK PENGGUNAAN DIESEL ENGINE 93 KW TERHADAP PERFORMA TURBOCHARGER PADA VARIASI KECEPATAN DAN BEBAN

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APPROVAL FORM

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BACHELOR THESIS

Submitted to Comply One of the Requirements to Obtain
Bachelor of Engineering Degree
On
Double Degree Marine Engineering (DD ME) program
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember (ITS)
Hochschule Wismar, University of Applied Science

Submitted by :

MUHAMMAD SIDIQ PRABOWO

NRP. 4212 101 021

Approved by Supervisor:

Ir. Aguk Zuhdi Muhammad Fathallah, M.Eng, Ph.D
NIP. 1956 0519 1986 10 1001

Benny Cahyono, ST, MT, Ph D
NIP. 1971 0110 1997 02 1001

Surabaya
December, 2016

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Hochshule Wismar, University of Applied Sciences

Submitted by

MUHAMMAD SIDIQ PRABOWO

NRP. 4212 101 021

Approved by Head of Marine Engineering Department

KEMENTERIAN RISET TEKNOLOGI DAN PENDIDIKAN
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
FAKULTAS TEKNOLOGI KELAUTAN
JURUSAN
TEKNIK SISTEM
PERKAPALAN

Dr.Eng. Muhammad Badrus Zaman, ST. MT.
NIP. 1977 0802 2008 01 1007

SURABAYA
January, 2017

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Hochschule Wismar, University of Applied Science

Submitted by

MUHAMMAD SIDIQ PRABOWO

NRP. 4212 101 021

Approved By
Representative of Wismar University in Indonesia

für

Dr.-Ing. Wolfgang Busse

Surabaya
January,2016

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Name	: Muhammad Sidiq Prabowo
NRP	: 4212 101 021
Bachelor Thesis Title	: The Effect of diesel engine 93 kW on Turbocharger performance at various speed and load
Department	: Marine Engineering

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PREFACE

Bismillahirrahmaanirrohiim

Alhamdulillahirabbilalamin, by the blessing of Allah SWT. The author is given strength and ease to accomplish the paper script in time. This paper, by title “The Effect of diesel engine 93 kW on Turbocharger performance at various speed and load “is submitted in fulfillment for Double Bachelor’s Degree Program in Institut Teknologi of Sepuluh Nopember and Hochschule Wismar.

The author realizes that this task was not done by one man’s efforts, but it was also supported by all sorts of sides surrounding the author. Therefore, the author would say thanks’ to:

1. My beloved family, my mother Sitti Maolae S.E for incomparable love, patience and prayers. My Father Ipda Subakir for her spirit and motivation of the author in completing this thesis.
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4. Dr.Eng.M.Badrus Zaman,S.T., M.T as the head of Marine Engineering department Institut teknologi sepuluh nopember.
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6. Benny Cahyono , ST. MT. Ph.D as the supervisor 2 who has guided the author and motivation to accomplish the thesis.
7. Lecture’s In Marine Engineering department who has given beneficial knowledge.

8. Dhena Huwaida as my girlfriend who has given me motivation to accomplish the thesis.
9. Friends 2012 DD forces who have provided support and motivation.
10. My friend Alvin, Dimas angga, Radhin, Danang, Hafid, Kaka, Fadhil, Teuku, Akram, Akbar, Arvian, Bintan, hakam, yasin, demi, dani, ilyas and other friends that writer can’t mention one by one.
11. Friends in the Laboratory of Marine Power Plant, MEAS, MMD, RAMS, and MMS who contribute in the completion of the thesis.
12. Friends 2012 Bismarck forces who have provided support and motivation.

Finally, the authors realize that this bachelor thesis is still not perfect yet. Therefore the authors expect some recommendation from the readers to make it better.

Surabaya, January 2017

Author

The Effect of Diesel Engine 93 kW on Turbocharger Performance at Various Speed and Load

Name : Muhammad Sidiq Prabowo

NRP : 4212 101 021

Department : Double Degree Marine Engineering (DD ME) Program

Supervisor : Ir. Aguk Zuhdi Muhammad F., M.Eng, Ph.D

Benny Cahyono, ST, MT, Ph D

Abstract

The purpose research is to know the effect variation load and speed of diesel engine on turbocharger characteristic. The analysis process was performed by using 1D model simulation. The simulation model covers all parts of the engine cycle consisting of intake, compression, power and exhaust. From the system input the load of diesel engine can variation with dynamometer. The simulation has held into several condition based on the engine rotation 800, 1000, 1200, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2200 RPM and the engine load 0% 20%, 40%, 60%, 80%, 100%, and 120%. Simulation by software is made to obtain the characteristics of engine performance such as torque, power, fuel consumption, on the engine rotation. Turbochargers used in the simulation are GT2052-1, GT2052-3. The result of simulation process is variable speed have a high impact to turbocharger efficiency. Variable speed can affect turbocharger performance around 1% until 6% every speed condition on simulation. Simulation process explain load have low impact to turbocharger efficiency. Variable load can affect turbocharger performance around 0,03% until 0,5% every load condition on simulation.

Simulation model show the high efficiency of turbocharger located on GT2052-1 at speed condition 1600 RPM and 0% load. The best output engine power, SFOC and torque from simulation show at turbocharger GT2052-3. The value of power, SFOC and torque are 96,82 kw, 228,02 g/kwh and 420,27 Nm respectively at full load condition and 2200 rpm speed.

Key Word *:Diesel Engine, performance, Efficiency turbocharger, simulation, modeling*

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CHAPTER 1
INTRODUCTION

1.1 Background

Development in science and technology is very quickly giving a big impact in human life in many areas of human life. This can see by the increasing number of equipment that has been created by human in variety of models. The growing number of equipment can be indicating the skill of human will be increased. One example in the field of machinery is turbocharger. The main function of turbocharger is to increase engine power by forcing extra air to combustion chamber inside the engine, so the amount of fuel burnt increase and make the combustion more perfect. Turbochargers not only help the engine to get more power but also reducing the exhaust gas emission. The main part of turbocharger consists of turbine, central hub, and compressor.

Turbocharger typically used on diesel engine, and when the engine running it carries a load and the load can affect to the engine and the turbocharger characteristic. Diesel engine used for marine propulsion, this is because the shape is compact and economical. For marine diesel engine with 93 kW power are needed for vessels with a tonnage between 15-20 GT (especially for fishing vessels). The fishing vessel usually using a turbocharger but the fishing vessel can carried different load from the fish, it can affect to turbocharger characteristic.

Related of the problems, this study will analyze the effect of speed and load of diesel engine 93 kW on turbocharger characteristic that have been designed. In analyzing the effect of speed and load of diesel engine 93 KW can be carried out by experimental and simulation. But experimental method is very expensive and also required a diesel engine that has been built / finished. Therefore, this final project is using simulation methods. Simulation method is a technique to obtain data to create a computer model of the motor being studied. The simulation results in the form of graphs and pictures that shows the parameters studied turbocharger performance.

1.2 Problem Formulation and Scope

Based on the description above, there is a few of problem formulation can be given:

1. How the impact variables load of diesel engine 93 KW on turbocharger performance?
2. How the impact variable speed of diesel engine 93 KW on turbocharger performance?

1.3 Scope of Problem

Based on the problem formulation and scope, there is a few scope of problem can be given:

1. The simulation using simulation modeling software.
2. Knowing the effect variable speed and load of diesel engine 93 KW on turbocharger performance.
3. Turbochargers used in the simulation are GT2052-1, GT2052-3.

1.4 Research Objectives

This bachelor thesis has purposes to :

1. Knowing the impact variable load of diesel engine 93 KW on turbocharger performance
2. Knowing the impact variable speed of diesel engine 93 KW on turbocharger performance

1.5 Research Benefit

Benefit of this research are :

1. To increase a knowledge about the effect variable load on turbocharger performance.
2. To increase a knowledge about the effect variable speed on turbocharger performance.

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CHAPTER 2
LITERATURE REVIEW

To better understand the effect of diesel engine 93 kW on turbocharger Performance at various load, existing study literature have been reviewed. Study literature the effect variation of load on turbocharger performance has proved have different efficiency in every different speed and load condition. This study literature review is about research already made previously and simulation software modeling.

2.1 Turbocharger Performance

Schieman (1992) say the job of turbocharger on diesel engine is to supply compressed air to the engine. The air, heated by the compression, passes through a cooler which reduces its temperature and increases its density. The air mass is compressed in the engine cylinder to a high pressure. Fuel is injected and burnt. The exhaust gases that are produced pass to the turbocharger's turbine, which driver the compressor.

Simatupang & Eriyanti (2014) make a research about *"pengaruh turbocharger terhadap performa mesin diesel di PLTD Titi Kuning PT.PLN Pembangkit Sumatera Utara Sektor Medan".* In the research Simatupang explain about turbocharger installation on the engine can increase performance of engine. Turbocharger is a mechanism for supplying air at a density that exceeds the density of atmospheric air into the cylinders for compressed in the compression step, so that the motor will increase, in addition to increased power, the turbocharger is also lower levels of air pollution due to combustion of these fuels with air occurs with perfect. In the research is carried out an analysis of price-effective and price (work produced after Overcoming loss) when installation turbocharger and not installation turbocharger to achieve 1500 rpm rotation. The results of this study show the effect of using turbocharger on diesel engine performance parameters such as: power, fuel use and efficiency thermal in such small capacity diesel engine vehicles.

Kusnadi, *(2010)* make a research about *"pengaruh penggunaan turbocharger terhadap unjuk kerja mesin diesel Type L300"* in the research explain about the effect of turbocharger installation to diesel engine performance, with installation expected turbocharger air entering the engine will be more, so as to increase engine power and help more perfect performance diesel engines. With the addition of a turbocharger or weighing machine will increase the speed, so no need to require more gas to run, automatically he speed will increase with the installation of this turbocharger. The methodology of his research is testing procedure to perform this test there must be some construction changes to the installation of the diesel engine turbocharger. The results of this analysis that the power generated before and after using a turbocharger.

Medica (2009) make a paper performance simulation of marine slow-speed diesel propulsion engine with turbocharger under aggravated conditions; explain on his paper a zero-dimensional model has been designed for assessing the quality and reliability of the diesel engine propulsion system under aggravated conditions. The model consists of components whose mathematical descriptions have been derived from basic laws of mechanics, thermodynamics, heat transfer and fluid dynamics, mutually correlated by flows for the transfer of mass and energy, for modeling using MATLAB 7.4.0. The output of this analyses and model can be used in finding better design characteristics and in expert operating systems which can analysis different conditions of the system beforehand and offer optimum operating conditions in order to prevent unwanted occurrences.

Rautenberg M., et al., (1983) these authors emphasize the heat transfer influence on the turbine power and on the compressor outlet temperature. The increase of this temperature leads to a density decrease, which isn't favorable to the engine volumetric efficiency. The usual isentropic efficiency is wrongly used. It doesn't define the aero dynamical quality of the compression, because it considers the heat transfers between the turbine, the compressor and the surrounding area. Thanks to experimental tests, the authors note a strong dependence between turbine inlet temperature and compressor outlet temperature. The geometrical turbocharger characteristics, mainly the distance between compressor and turbine, appear to influence greatly the heat fluxes.

Jung M., et al., (2002 suggest a parameterization of turbine maps to obtain the behavior of the turbine in its actual environment. They study heat losses considering the turbine as an exchanger which efficiency is derived from the manufacturers map. Aerodynamic and heat efficiencies are then added to obtain the global efficiency.

Muhawwaq (2016) explain about performance prediction of marine diesel 4 cycle 93 KW with simulation method engine performance predictions made based on variations in engine speed, that is 1000, 1200, 1400, 1500, 1600, 1700, 1800, 2000, 2200, 2300 rpm. At each round is done loading 20%, 40%, 60%, 80%, 100% and 110%. The simulation results is in the form of engine performance characteristics (e.g., torque, bsfc, and power), and the combustion process (such as the release of heat, pressure, ignition delay).

Pradana, (2016) explain about choosing turbocharger in main engine 93 KW to increase performance and the power of the engine. This study was use simulation methods. The first step from this study taken was to collect data specifications of the marine diesel engine. Performance predictions obtained by modeling the engine in simulation software. Simulation covers the entire engine from the dimensions, air flow in-out, fuel injection systems, etc. An engine performance prediction was done by installation of three turbochargers with different specifications. The simulation process was made into several cases based on the engine speed 800, 1000, 1200, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2200 RPM. Turbochargers used in the simulation are GT2052-1, GT2052-3.

This research was conducting a study about the effect of diesel engine 93 kW on turbocharger performance at various speeds and load.

2.2 Prediction turbocharger Performance using simulation

There are several methods for predicting the performance of the diesel engine-based simulation.

Riegler & Bargende (2002) states that the GT-POWER is software for the simulation model of the steady state and transient and can be used to analyze the machines. This software can be applied to all types of internal combustion engines and provides a variety of models of components and other advanced concepts. GT-POWER running based on the dynamics of one-dimensional gas, flow, heat transfer in piping systems and other components on the machine Engine power rating usually indicates the largest, torque, and the maximum speed that can be given machine and provide economic value, reliability, and durability are satisfactory.

Smith & Cothren (1999) explain about the steady speed volumetric efficiency for the spark ignition engine in transient operation. A computer model simulation is using of this research. A model has developed for a 3.9 liter V8 SI engine by GT Power code computer simulation software and Ring manifold model was validated with the baseline engine. Validation was done for transient automotive internal combustion engine volumetric efficiency at wide open throttle valve condition. It is shown that the efficiency of the engine volumetric responds almost quasi-stable under operation transient thus justifying the assumption of a correlation between the speed steady and transient data.

Bingham (1987) explain about computer simulations have been used widely in the development of the intake and exhaust systems. However, considerable efforts can still have needed to identify a system that will achieve optimum cylinder charging and scavenging characteristics with minimum pumping losses.

Boretti G & Bickel M, (1996) explain about the use of computer simulation which can be used for optimization of high performance. To optimize of high performance can be done by naturally aspirated compression ignition engines such as stationary engines and ship engines. A comprehensive multi-zone thermodynamic model, developed in order to examine the effect of insulating the combustion chamber of diesel engine.

Badami (2002) research about application of computational methods for the development of a high performance four stroke engine using a simulation model built in GT Power simulation software. The simulation model was used to simulate the engine performance at full load and the data predicted from computer simulation have been compared, validated with experimental data. Also computer simulation techniques were applied to develop an exhaust system with experimental data.

From the previous research already done, this thesis is more suitable using design method based on size of diesel engine that has been designed before. Output of turbocharger performance is graphic compressor performance and turbine performance. The simulation-based GT-power software simulation is used by engine maker and supplier engine and vehicles. This simulation software is suitable for analysis various problem on machine and turbocharger.

2.3 Compressor Map

The compressor map is a graph that describes a particular compressor's performance characteristics, including efficiency, mass flow rate, boost pressure capability, and turbo speed. Shown the figure 2.1 that identifies aspects of a typical compressor map:

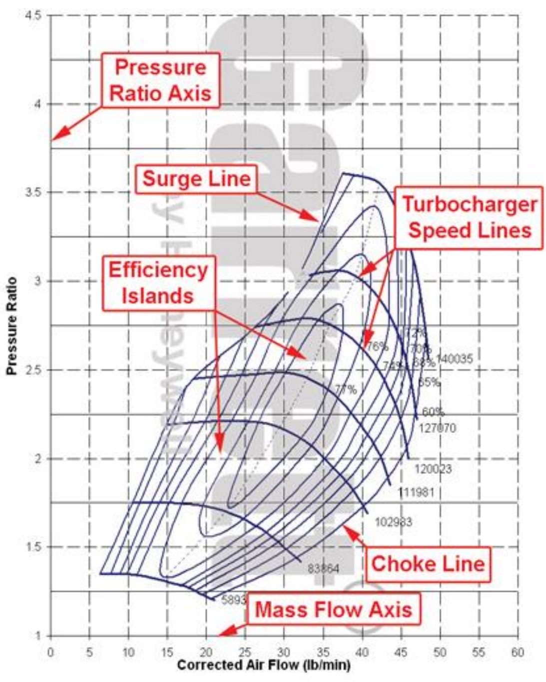


Figure 2. 1 Compressor map
(http://turbobygarrett.com/)

CHAPTER 3
METHODOLOGY

The methodology is a description of the steps carried out in a study. Methodology in this thesis includes all activities carried out to solve a problem on this thesis. In general, the method used in problem solving is diesel engine simulation modeling. Detail activities of this research are:

1. Literature Study
2. Data collection diesel engine 93 Kw and Turbocharger GT2052-1 and GT2052-3
3. Simulation modeling diesel engine 93 KW, turbocharger and dynamometer for variation of load
4. Running simulation
5. Validation and modeling analysis

3.1 Flow Diagram

Flowchart diagram activities of this research can be seen in figure 3.1.

3.2 Literature Study

The literature study be held by searching paper or journal about working principle turbocharger, characteristic turbocharger with variation speed and load, the effect variation speed and load to turbocharger performance. The goal is to strengthen the basic theory problems as in the analysis. Literature used can be collected from websites, books, journals, papers, final project, and other related sources.

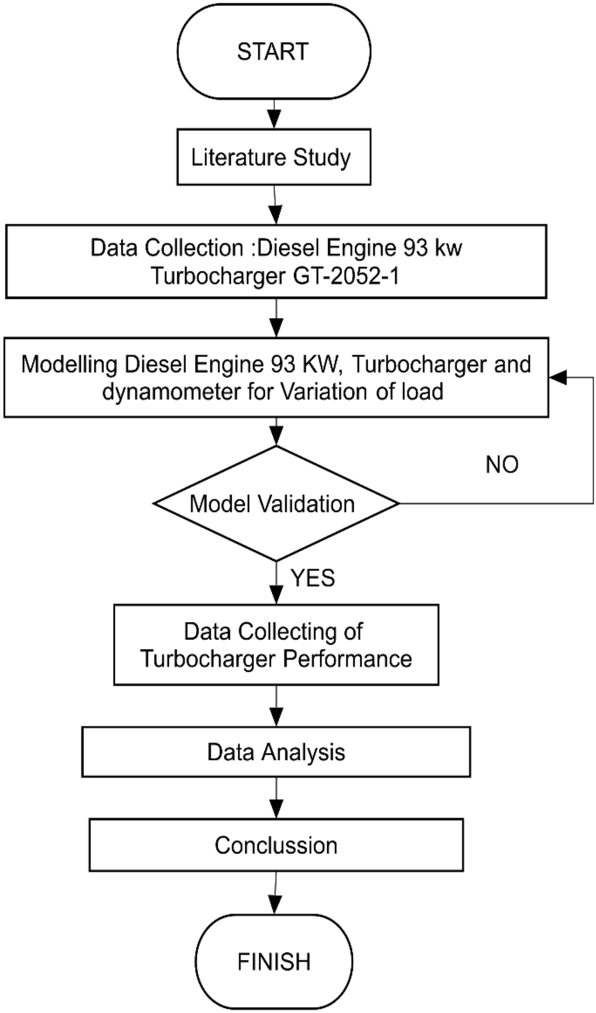


Figure 3. 1 Flowchart bachelor thesis

3.3 Data Collection

The data used in this bachelor thesis is the data of Marine Diesel Engine designed by Juniono Raharjo, Arvian Pradana and Abdul Hakam students of Marine Engineering Department – ITS Surabaya. The data for this analysis will be collected from engine specification, turbocharger specification and dynamometer for various of load. The required data is as follows:

- Diesel engine 93 KW Specification are brand, engine Model, no. of Cylinder, rated power, displacement, bore, stroke, inlet valve, outlet valve, compression ratio, firing order, exhaust System, air intake system, lubrication system, fuel System.
- Turbocharger Specifications are brand, model, compressor, turbine, cooling and dimension.
- Dynamometer using for variation of load.

3.4 Modeling diesel engine 93 kW, turbocharger and dynamometer.

Modelling marine diesel engine 93 KW performed using software. Modeling done by similar real diesel engine, so that the result obtained will be possible for analysis. Modeling and simulation done based on diesel engine specification that has been designed previously. Engine specification see on table 4.1. Modeling and simulation done in several stages. Modeling steps are:

3.4.1 Modeling measurement

The first thing to do before do modeling and simulation is measurement of diesel engine has been design previously. This is due because the engine required detail data relating dimension of diesel engine and environment condition.

3.4.2 Modeling each part

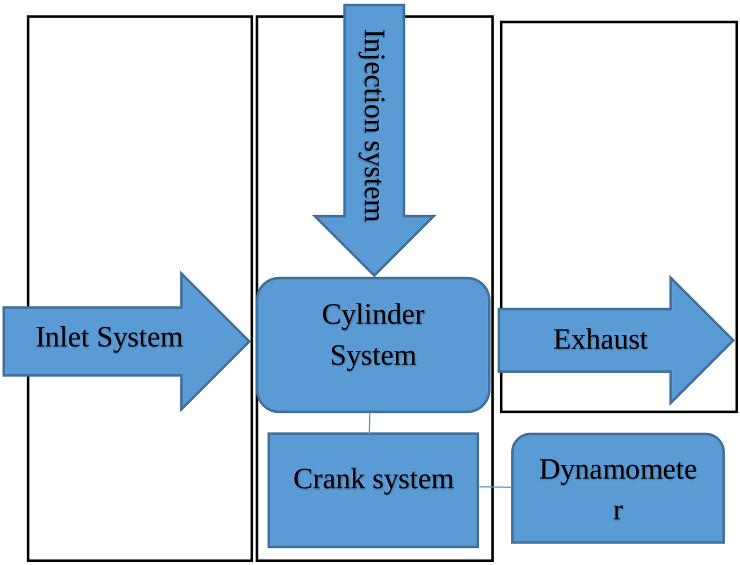


Figure 3. 2 Scheme modeling marine diesel

3.4.3 Object definition

The modeling diesel engine must be made by inserting the data in accordance with required parameter. It is called with definition object. The model divided 3 system are intake system, cylinder system and system fuel injection, and the system exhaust. The model 1D simulation can be added dynamometer for variable load condition.

a. Intake system, there are several object can definition. There are inlet environment, piping system, compressor, Inter cooler, Intake runner, Intake port, and Intake valve.
b. Cylinder system, crank and fuel injection system, there are several component can definition. There are cylinder, fuel injector, engine crank train and dynamometer.

c. Exhaust system, there are several component can definition. There are exhaust valve, exhaust port, Exshaust runner, Turbine and End environment.

3.4.4 Connecting each part

After object definition is completed, then enchaining each part. Objects arranged in accordance with the order of the system. The complete mode marine diesel 93 Kw see on figure 3.2.

3.5 Model Validation

At this stage, the output model from simulation process not exactly resulted the correct data of engine performance. The output model obtained as a result from engine simulation might be had some of error. So we have to repeat the step of the simulation stage to find failures and corrected the input data. If the model has been obtained correctly, then we can go to the next step. Parameter used as a reference of diesel engine power by Abdul hakam muhawwaq (2016) is 40.3462 KW at no turbocharger condition. If the power is equal or greater the model is right.

3.6 Data Collecting of Turbocharger Performance

The modeling simulation is completed, and then the model is ready to be simulated. Marine diesel engine 4 stroke 93 Kw is simulation with various speeds and load. The data output obtained operating line turbo compressor-engine and operating line turbine- engine. From the operating line, efficiency, mass flow range, boost pressure capability, turbo speed of compressor and turbin every conditions can be explained.

3.7 Data Analysis

If the data have been obtained, it can be carried to next step is analysis data. Data output from model run at speed 800, 1000, 1200, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2200 RPM. The simulation were conducted with different loads, begin from 0%, 20%, 40%, 60%, 80%, 100% and 20% overload. This is done to find out more detail the performance of turbocharger.

3.8 Conclusions and Recommendation

Conclusions are expected in this thesis is able to answer the problem. This thesis aims to know the impact variation speed and load of diesel engine 93 KW on turbocharger characteristic.

CHAPTER 4
DISCUSSION AND RESULTS

In this chapter exsplain about discussion and analysis of this research from result simulation software.

4.1 Engine Spesification Data Used

Simulation done by marine diesel engine which has been design in previous study. The following is a specification of the engine data will be used in the simulation. Figure 4.1. design engine by Raharjo :

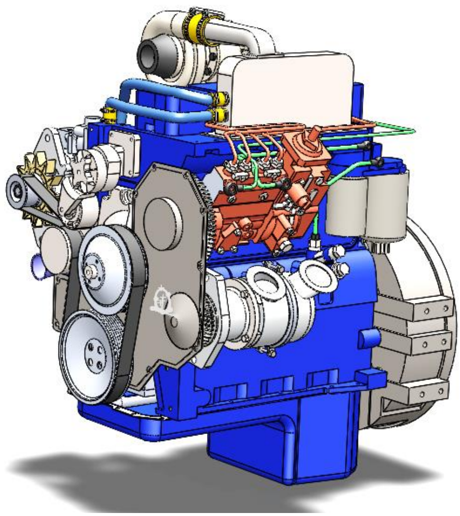


Figure 4.1 Isometry design of engine 4 stroke, 4 cylinder 93 kw (Raharjo,2015)

In this table explain about engine data information. Engine data information explain about specification engine using in this simulation. In this simulation using diesel engine

Cummins model 4BTA3.9-M125. For more information, see table 4.1:

Table 4. 1 Engine Data Information

Engine Type	Diesel engine
No. Of cylinder	4
Bore	102 mm
Stroke	120 mm
Inlet Valve	45 mm (clearence =0,25 mm)
Outlet Valve	43 mm (clearence =0,51 mm)
Displacement	3.9 lt
Compression Ratio	1: 16.51
Cooling system	Air
Firing order	1-3-4-2
Length of connection Rood	191,7 mm

Source : (http://turbobygarrett.com/)

Every simulation process, simulator software can show multiple output file containing simulation results in various format. The result output can using for performance analysis of the turbocharger. Output of simulation showing on software aplication, can using for showing grafic and data output. At the end of simulation process, report that summarizes the simulation result can be made. This report contains the important information about simulation and simulation results in the form of graph and table.

The simulation process will be carried out at different speeds (RPM). The installation model will run at speeds 800,1000,1200 ,1400, 1500, 1600, 1700, 1800, 1900, 2000, 2200 RPM. Simulation will be done using variation of load, start from 0%, 20%, 40%, 60%, 80%, 100% And 120% From the simulation result will be analyzed to know the effect of diesel engine 93 KW to turbocharger performance with variation of load.

4.2 Turbocharger I (GT2052-1)

Figure 4.2 explain about model turbocharger GT 2052-3. Turbocharger using on simulation model.

Figure 4. 2 Turbocharger Garrett GT2502 (727264-1) (http://turbobygarrett.com/)

4.2.1 Turbocharger I Specification

This table 4.2 explain about turbocharger GT-2052 (72726-1) specification example brand, model, cooling, bearing and etc.

Table 4. 2 Turbocharger specification Garrett GT2502-1

Brand	**Garrett by Honeywell**
Model	GT2502 (727264-1)
CHRA PN	451298-45
Bearing	Journal
Cooling	Oil
Compressor	Inducer : 37.6 mm Exducer : 52.2 mm Trim : 52 A/R : 0.51
Turbine	Wheel : 47.0 mm Trim : 72

	A/R : 0.50 Housing inlet : Single
Wastegate	Internal
Water Cooled	No
Ball Bearing	No

Source : (http://turbobygarrett.com/)

4.2.2 Compressor Map (GT2052-1)

Compressor map is a graph that describes a particular compressor's performance characteristics, including efficiency, mass flow range, boost pressure capability, and turbo speed. Figure 4.3 that identifies aspects of compressor map GT 2052-1:

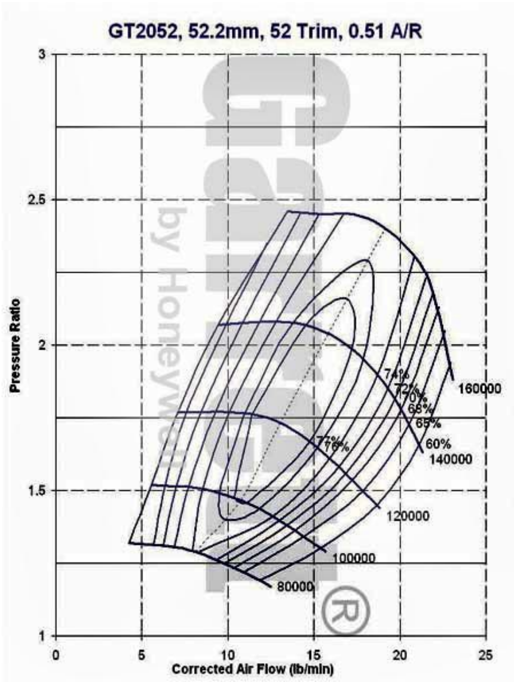


Figure 4. 3 GT2052 (727264-1) Compressor Map
(http://turbobygarrett.com/)

4.2.3 Turbocharger Dimension (GT2052-1)

Dimension of turbocharger GT-2052 exsplain about compressor inlet, compressor outlet, oil inlet, turine inlet, turbine outlet, oil outlet and all turbocharger measurement. For detail measurement see on figure 4.4:

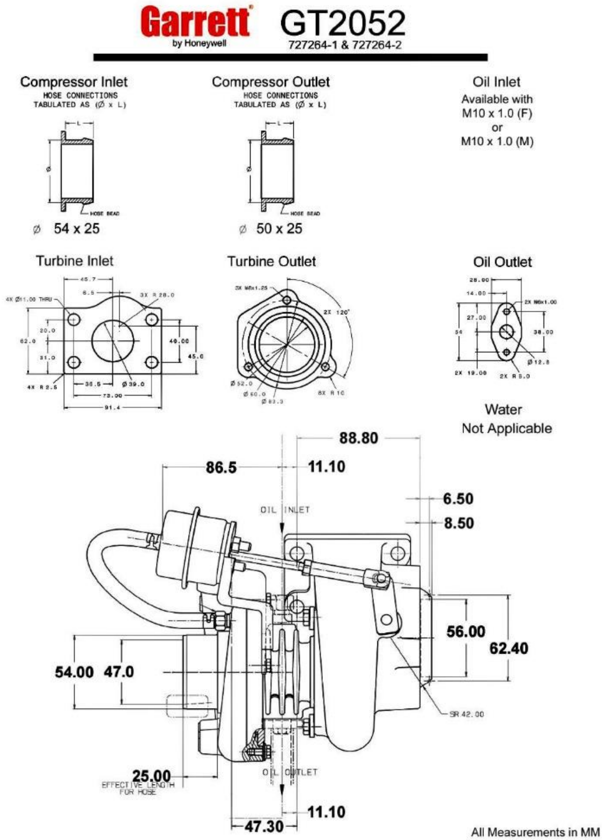


Figure 4. 4 Garrett GT2502(727264-1) dimension
(http// www. turbobygarrett.com)

4.2.4 Modeling load on engine model with turbocharger G2052-1

Load in engine every speed and load condition is different. Load is weight, quantity, or nature of what is being carried by a transporting vehicle. This simulation divided load into seven categories 0%, 20, 40, 60, 80, 100%and 120% load. Table 4.3 is torque of engine was use on simulation model :

Table 4. 3 Load condition at 100%, 80% and 60% load with turbocharger GT2052-1

100 %		**80 %**		**60 %**	
RPM (rpm)	**Torque (N.m)**	**RPM (rpm)**	**Torque (N.m)**	**RPM (rpm)**	**Torque (N.m)**
800	267.47	800	213.97	800	160.48
1000	294.26	1000	235.41	1000	176.55
1200	327.31	1200	261.85	1200	196.39
1400	366.68	1400	293.34	1400	220.01
1500	386.42	1500	309.13	1500	231.85
1600	402.84	1600	322.27	1600	241.70
1700	416.00	1700	332.80	1700	249.60
1800	423.59	1800	338.87	1800	254.16
1900	427.03	1900	341.62	1900	256.22
2000	426.36	2000	341.09	2000	255.82
2200	406.37	2200	325.10	2200	243.82

Source: Author running simulation and calculation

The table 4.3 is show the value of torque on some condition. Value of torque at 100% load take it by output simulation model with engine and turbocharger GT2052-1. From output simulation model high torque located on 1900 rpm at 100% load.

Torque at 80% and 60% load get from calculation. The formula of value torque except 100% is:

$$\tau_{load} = Load \; x \; \tau_{100\%}$$

Equation 4.1

Where, τ_{load} = Value of torque at specific condition

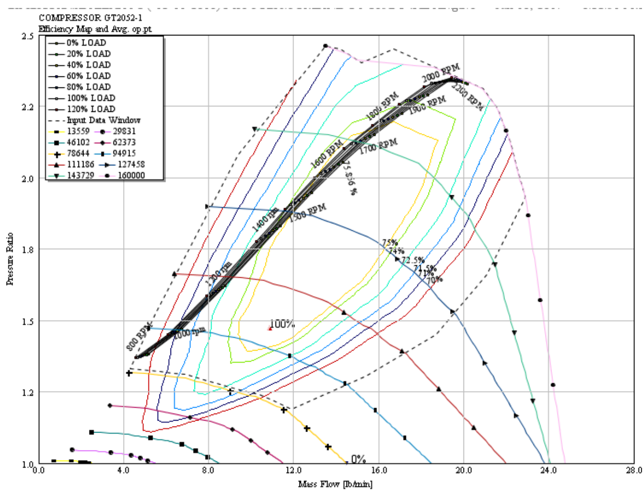
$Load$ = Load at one condition

$\tau_{100\%}$ = Torque at 100% condition

Running simulation model using to get the value of torque every speed and load condition except 100% load. Dynamometer using for input load to the engine. model simulation running and get the output data operating line turbocharger compressor engine and operating line turbo compressor engine every speed and load condition.

4.2.5 Operating line turbocharger-compressor GT2052-1 with variable Speed and Load

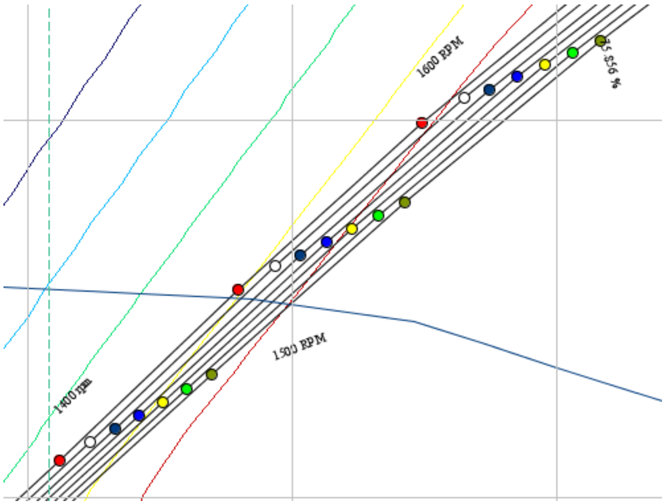
The graph 4.1 is shown the operating line of turbocharger compressor GT2052-1 to the engine. Operating line turbocharger compressor to the engine data is used to verify the installation of the turbocharger on the engine.



Graph 4. 1 Operating line turbocharger compressor GT 2052 -1 With Variable speed and Load

From graph 4.1 show operating line turbo compressor (compressor efficiency map-corrected), X line is mass flow (lb/min) and Y line is pressure ratio. Multicolour on the graph show efficiency of compressor. From the graph, the most efficiency of turbocharger compressor at 0% load and 1600 RPM with 75,856 %.

Magnifition of graph 4.1 is graph 4.2. the graph 4.2 explain operating line turbocharger GT2052-1 with variable speed 1400,1500,1600 RPM and all variable load condition.

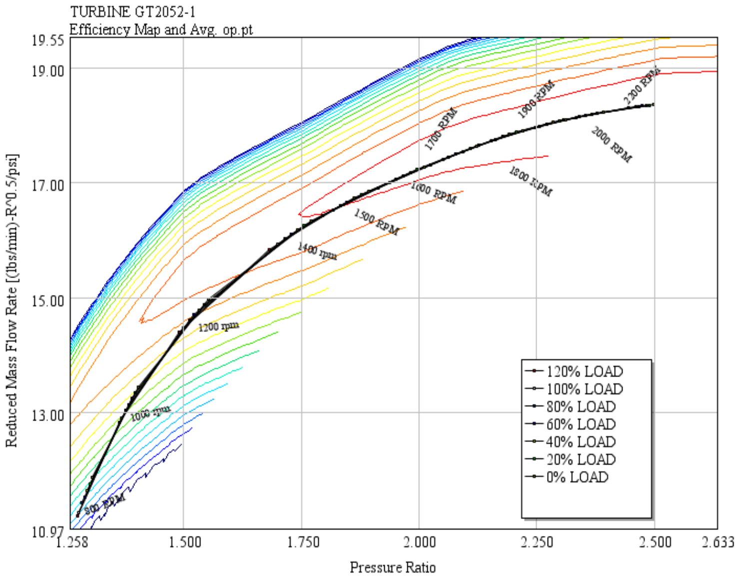


Graph 4. 2 Operating line turbocharger compressor engine GT2052-1 With Variable speed 1400,1500,1600 RPM and variable load condition

The graph 4.2 operating line turbocharger-compressor GT2052-1. The dots from graph 4.2 explain about variable load. Line on the graph show the same load every different condition.

4.2.6 Operating Line Turbo Turbine Engine (GT 2052-1) With Variable Load

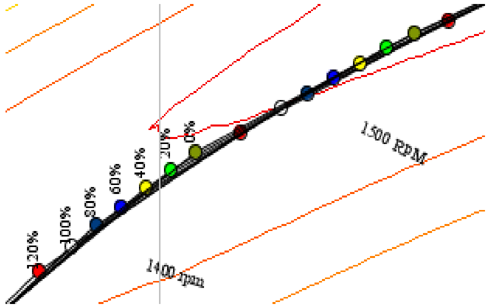
Graph 4.3 is show the operating line of turbocharger turbine. This graph 4.3 explained about turbine efficiency map, X line is mass flow (lb/min) and Y line is pressure ratio. Multicolour on the graph show efficiency of compressor.



Graph 4. 3 Operating line turbocharger turbine GT2052-1 with Variable Load

From the graph 4.3, the most efficiency of turbocharger turbine at 0% load and 2200 RPM with 72,2177 %. The colour on graph show eficiency of turbocharger.

This graph 4.4 explain about operating line turbocharger compressor engine GT 2052-1 With Variable speed 1400,1500 RPM and variable load condition.

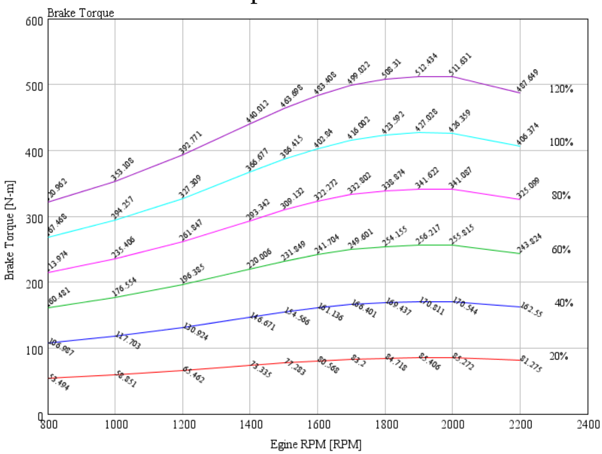


Graph 4. 4 Operating line turbocharger turbine GT2052-1 With Variable speed 1400, 1500 RPM and variable load condition

The variable load is all dots on the graphic. Seven dots on the graph show one speed condition. Red dots is 120% load, white dots is 100% load and etc.

4.2.7 Engine Brake Torque with turbocharger GT 2052-1

Graph 4.5 show relationships between torques and engine RPM at variation speed and load condition.

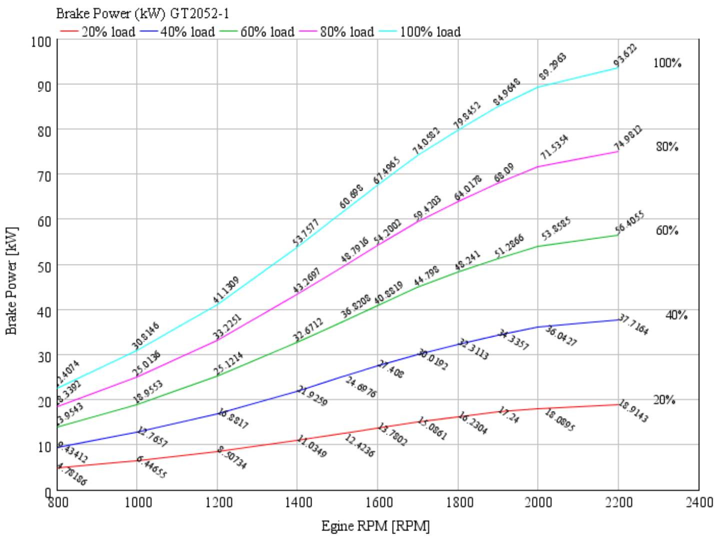


Graph 4. 5 Engine Brake Torque with turbocharger GT2052-1

From the graph 4.5 show maximum brake torque located on 1900 RPM at 120% load. The value of torque is 512,43 Nm. The lowest torque is at 800 RPM at 20% load with a value of 53,494 Nm. The graph is show value of torque increase until 1900 RPM. After it reach the highest torque at 1900 RPM then the torque decreased again to maximum revolution of the engine.

4.2.8 Engine Brake Power with turbocharger GT 2052-1

The graph 4.6 show the power output of engine with installation turbocharger GT2052-1.

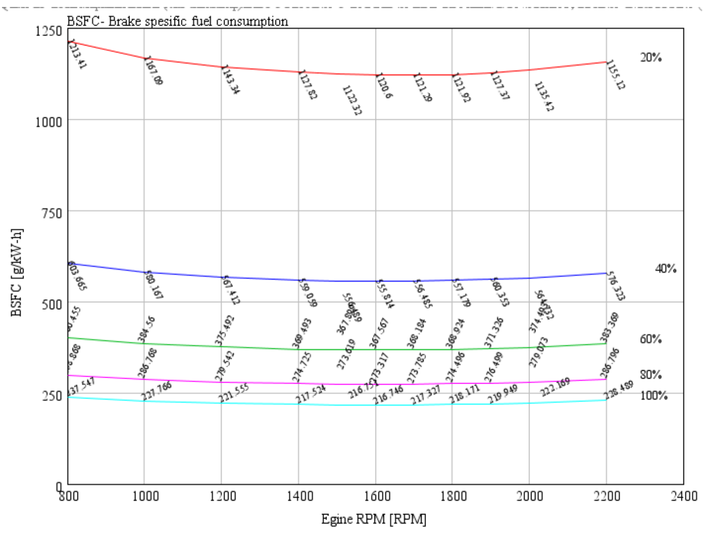


Graph 4. 6 Graphic engine RPM vs Engine Brake Power with turbochargerGT2052-1

The power output measured at the engine's flywheel. Brake power result obtained from the simulation, the low power is 4,78 kW at 800 RPM and 20% load. The higest power generated at 2200 RPM with a value of 93.622 Kw at full load condition. As the increases of engine revolution, power generated will be increased until certain point and the the power will decreased again.

4.2.9 Engine BSFC with turbocharger GT 2052-1

Brake specific fuel consumption (BSFC) is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft, power. This graph 4.7 is showing specific fuel oil consumption every speed and load condition.



Graph 4. 7 Graphic engine RPM vs BSFC with turbocharge GT2052-1

The result from the graph is shown the fuel consumption in every engine rotational speed. From the graph show the high consumption is 1213,41 g/kwh. The low consumption is 216,75 g/kwh. The high fuel consumption located on 20% load and 800 RPM and lower consumption located on 1600 RPM at full load condition.

4.3 Turbocharger II (GT2052-3)

Figure 4.5 explain about model turbocharger GT 2052-3. Turbocharger using on simulation model.

Figure 4. 5 Turbocharger Garrett GT2502-3
(http://turbobygarrett.com/)

4.3.1 Turbocharger II Specification

Table 4.4 is explaining about turbocharger GT 2052-3 specification example brand, model, cooling, bearing and etc.

Table 4. 4 Turbocharger specification GT 2052-3

Brand	**Garrett by Honeywell**
Model	GT2502 (727264-1)
CHRA PN	451298-44
Bearing	Journal
Cooling	Oil
Compressor	Inducer : 36.1 mm Exducer : 52.2 mm Trim : 48

	A/R	: 0.51
Turbine	Wheel Trim A/R Housing inlet	: 47.0 mm : 72 : 0.50 : Single
Wastegate	Internal	
Water Cooled	No	
Ball Bearing	No	

Source : (http://turbobygarrett.com/)

4.3.2 Compressor Map (GT2052-3)

This is a compressor map GT 2052-3. This compressor map is a graph that describes a particular compressor's performance characteristics, including efficiency, mass flow rate, boost pressure capability, and turbo speed. Shown below is a figure 4.3 that identifies aspects of compressor map GT 2052-3:

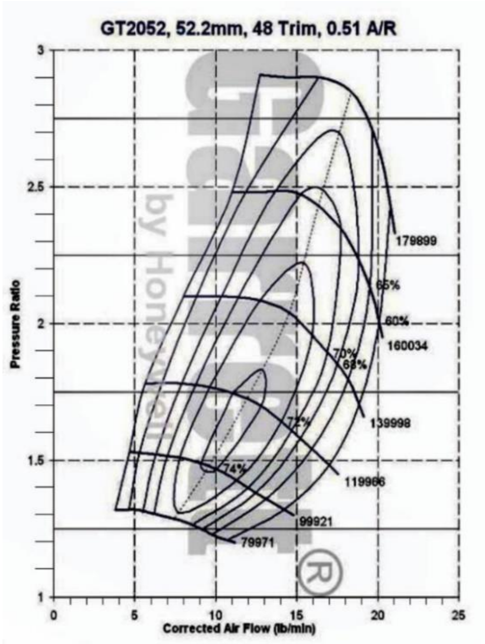


Figure 4. 6 GT2052-3 Compressor Map
(http://turbobygarrett.com/)

4.3.3 Turbocharger Dimension (GT2052-3)

This is a dimension of turbocharger GT2052-3, In this figure exsplain about compressor inlet, compressor outlet, oil inlet, turine inlet, turbine outlet, oil outlet and all turbocharger measurement. For detail can see in figure 4.4:

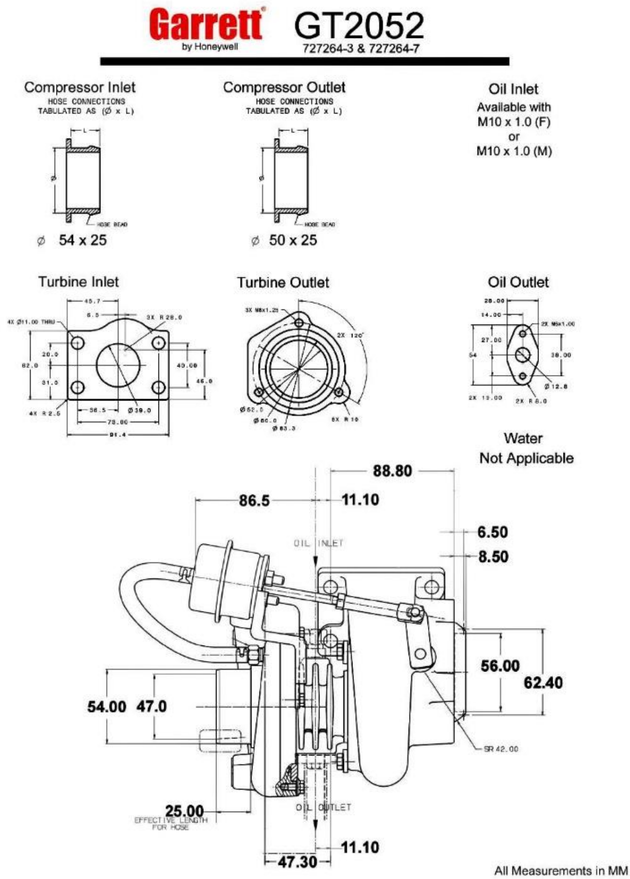


Figure 4. 7 Garrett GT2502(727264-3) dimension
(http// www. turbobygarrett.com)

4.3.4 Modeling load on engine model with turbocharger G2052-3

Load in engine every speed and load condition is different. Load is weight, quantity, or nature of what is being carried by a transporting vehicle. This simulation divided load into seven categories 0%, 20, 40, 60, 80, 100%and 120% load. Table 4.5 is torque of engine was use on simulation model :

Table 4. 5 Load condition at 100%, 80% and 60% load with turbocharger GT2052-3

100 %		80 %		60 %	
RPM (rpm)	**Torque (N.m)**	**RPM (rpm)**	**Torque (N.m)**	**RPM (rpm)**	**Torque (N.m)**
800	293.74	800	234.99	800	252.16
1000	327.44	1000	261.96	1000	268.04
1200	370.43	1200	296.34	1200	271.89
1400	422.43	1400	337.94	1400	275.00
1500	444.81	1500	355.85	1500	276.46
1600	460.34	1600	368.27	1600	276.20
1700	460.76	1700	368.61	1700	266.89
1800	458.34	1800	366.67	1800	253.46
1900	453.15	1900	362.52	1900	222.26
2000	446.74	2000	357.39	2000	196.47
2200	420.27	2200	336.22	2200	176.24

Source: Author running simulation and calculation

The table 4.5 is show the value of torque on some condition. Value of torque at 100% load take it by output simulation model with engine and turbocharger GT2052-3. From output simulation model high torque located on 1900 rpm at 100% load.

Torque at 80% and 60% load get from calculation. The formula of value torque except 100% is:

$$\tau_{load} = Load\ x\ \tau_{100\%}$$

Equation 4.2

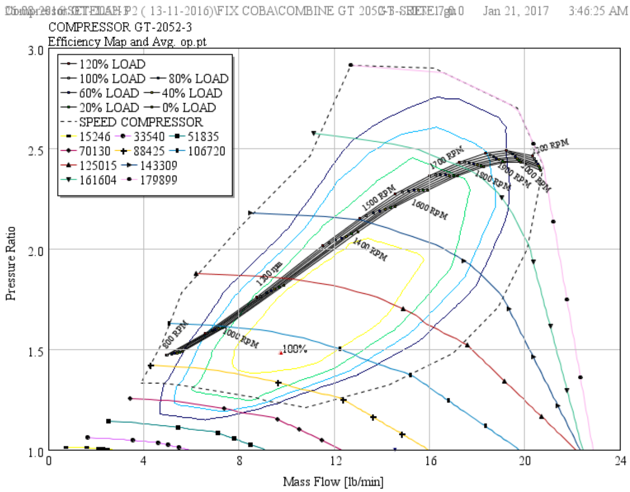
Where, τ_{load} = Value of torque at specific condition
$Load$ = Load at one condition
$\tau_{100\%}$ = Torque at 100% condition

Running simulation model using to get the value of torque every speed and load condition except 100% load. Dynamometer using for input load to the engine. Model simulation running and get the output data operating line turbocharger compressor engine and operating line turbo compressor engine every speed and load condition.

4.3.5 Operating line turbocharger-compressor GT2052-3 with variable Speed and Load

Graph 4.8 is shown the operating line of turbocharger compressor GT2052-3 to the engine. Operating line turbocharger compressor to the engine data is used to verify the installation of the turbocharger on the engine.

From graph show operating line turbo compressor (compressor efficiency map-corrected), X line is mass flow (lb/min) and Y line is pressure ratio. Multicolour on the graph show efficiency of compressor.

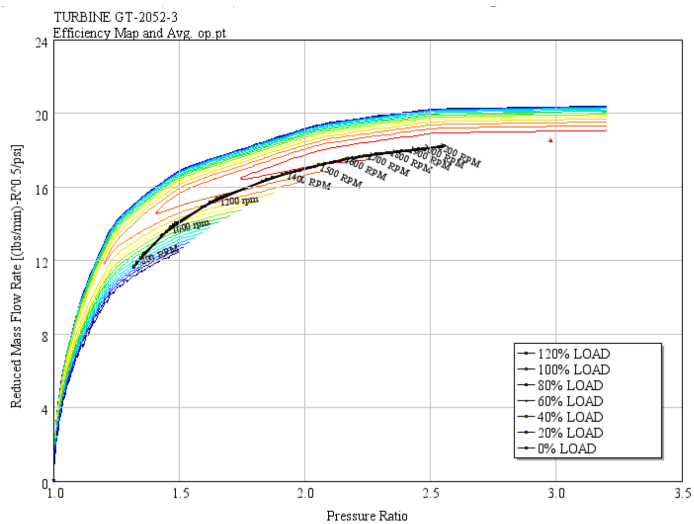


Graph 4. 8 Operating line turbocharger compressor GT 2052 -3 With Variable speed and Load

The graph 4.8 operating line turbocharger-compressor GT2052-3. The dots from graph is variable load and Line on the graph show the same load every different condition. From the graph, the most efficiency of turbocharger compressor at 0% load and 1400 RPM with 71,1501%.

4.3.6 Operating Line Turbo Turbine Engine (GT 2052-1) With Variable Load

Graph 4.9 show the operating line of turbocharger turbine. This graph 4.3 is explaining about turbine efficiency map, X line is mass flow (lb/min) and Y line is pressure ratio. Multicolour on the graph show efficiency of compressor.

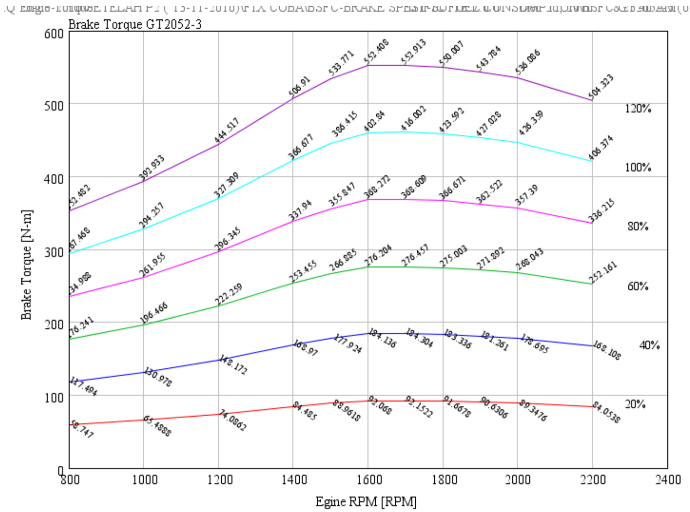


Graph 4. 9 Operating line turbocharger turbine GT2052-1 With Variable Load

From the graph show the most efficiency of turbocharger turbine at 0% load and 2200 RPM with 72,2026 %. The colour on graph show eficiency of turbocharger. The variable load is all dots on the graphic. Seven dots on graphic show one speed condition.

4.3.7 Engine Brake Torque with turbocharger GT 2052-3

Graph 4.10 show relationships between torque and engine RPM at variation speed and load condition.



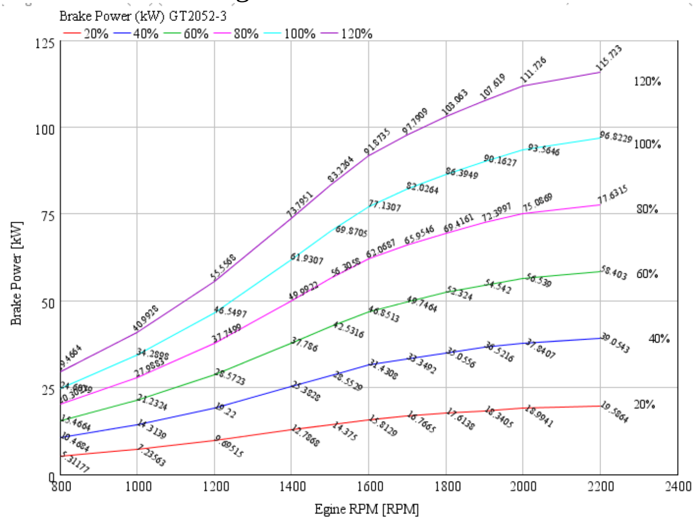
Graph 4. 10 Engine Brake Torque with turbocharger GT2052-3

From the graph 4.10 show maximum brake torque located on 1900 RPM at 120% load. The value of torque is 552,408 Nm. The lowest torque is at 800 RPM at 20% load with a value of 85,27 Nm. The graph is show value of torque increase until 1600 RPM. After it reach the highest torque at 1600 RPM then the torque decreased again to maximum revolution of the engine.

4.3.8 Engine Brake Power with turbocharger GT 2052-3

The graph 4.11 show the power output of engine with installation turbocharger GT2052-3.

The graph 4.11 show the power output of engine with installation turbocharger GT2052-3.

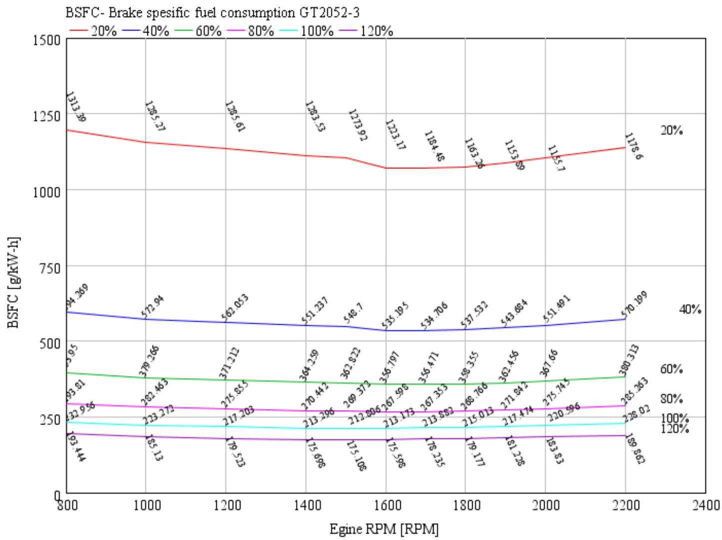


Graph 4. 11 Graphic of engine RPM VS Engine Brake Power with turbochargerGT2052-1

The power output measured at the engine's flywheel. Brake power result obtained from the simulation, the low power is 5,31 kW at 800 RPM and 20% load. The higest power generated at 2200 RPM with a value of 96,88 Kw at full load condition. As the increases of engine revolution, power generated will be increased until certain point and the the power will decreased again.

4.3.9 Engine BSFC with turbocharger GT 2052-3

Brake specific fuel consumption (BSFC) is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft, power. This graph 4.7 is showing specific fuel oil consumption every speed and load condition.



Graph 4. 12 Graphic engine RPM vs BSFC with turbocharge GT2052-3

The result from the graph is shown the fuel consumption in every engine rotational speed. From the graph show the high consumption is 1195,34 g/kwh. The low consumption is 212,81 g/kwh. The high fuel consumption located on 20% load and 800 RPM and lower consumption located on 1500 RPM at full load condition.

4.4 Turbocharger - Engine Discussion

4.4.1 Engine installed with GT2052-1 Turbocharger

Based on strandline performance output on GT2502-1 compressor and turbine map obtained the data output as shown 4.6 :

Table 4. 6 Turbine and Compressor output GT2052-1 Turbocharger on 100% load

Type of Device	Compressor	Turbine
Speed [RPM]	165365	165365
Pressure Ratio (static)	2.38	2.41
Pressure Ratio	2.35	2.46
Mass Flow Rate [kg/s]	0.14	0.15
Power [kW]	16	22.1
Efficiency [%]	73.9	72
Inlet Pressure [bar]	0.95	2.89
Outlet Pressure [bar]	2.25	1.2
Inlet Temperature [K]	297	896
Outlet Temperature [K]	408	768
Map PR Exceeded/Stalled ?	NO	NO
PR less than 1.0 ?	NO	NO

Source: Output simulation modelling with turbocharger GT 2052-1

Table 4. 7 Turbocharger GT2052-1 – Engine matching output

LOAD	RPM	Brake Power (kW)	SFOC (g/kWh)	TORQUE (Nm)
100%	2200	93.622	228.489	406.374

Source: Output simulation modelling with turbocharger GT 2052-1

Table 4.7 is the output results of engine performance to turbocharger at 100% load. Turbocharger shaft speed is 165365 RPM at maximum load. Turbocharger compressor generates power by 16 kW, and turbine by 22.1 kW. Average efficiency engine performance to turbocharger is 73.9%, with turbine efficiency 72%. The power generated at 2200 RPM of the engine is 93.622 kW. Fuel consumption used by 228.489 g/kWh, with torque value of 406.374 Nm.

4.4.2 Engine installed with GT2052-3 Turbocharger

Based on the strandline performance output on GT2502-3 compressor and turbine map obtained the data output as shown above

Table 4. 8 Turbine and Compressor output GT2052-3 Turbocharger on 100% load

Type of Device	Compressor	Turbine
Speed [RPM]	178662	178662
Pressure Ratio (static)	2.48	2.48
Pressure Ratio	2.45	2.54
Mass Flow Rate [kg/s]	0.15	0.15
Power [kW]	21.1	23.6
Efficiency [%]	61.4	72.1
Inlet Pressure [bar]	0.94	3.01
Outlet Pressure [bar]	2.34	1.21
Inlet Temperature [K]	297	898
Outlet Temperature [K]	437	766
Map PR Exceeded/Stalled ?	NO	NO
PR less than 1.0 ?	NO	NO

Source: Output simulation modeling with turbocharger GT 2052-3

Table 4. 9 Turbocharger – Engine matching output GT2052-3

LOAD	RPM	Brake Power (kW)	SFOC (g/kWh)	TORQUE (Nm)
100%	2200	96.823	228.489	406.374

Source: Output simulation modelling with turbocharger GT 2052-3

Table 4.9 is the output results of engine performance to turbocharger at 100% load. Turbocharger shaft speed is 178662 RPM at maximum load. Turbocharger compressor generates power by 21.1 kW, and turbine by 23.6 kW. Average efficiency engine performance to turbocharger is 61.4%, with turbine efficiency 72.1%. The power generated at 2200 RPM of the engine is 96.823 kW. Fuel consumption used by 228.023 g/kWh, with torque value of 420.629 Nm.

4.5 Turbocharger – Engine Matching Discussion

Based on the performance of the engine which had been installed by a different turbocharger, there are differences between every engine power output results:

4.5.1 Turbocharger GT2052-1 output result

The first turbocharger installed resulted compressor efficiency of 73.933% with turbine efficiency of 72.022%. Maximum power output of the engine which installed with GT2502-3 turbocharger is equal to 93.622 kW or 125.549 HP at 2200 RPM. Boost pressure value at this point is 2.247 bar with a temperature of 408.01 K. This turbocharger generated power not as high as first turbocharger installed, but the efficiency of the compressor is greater.

4.5.2 Turbocharger GT2052-3 output result

The second turbocharger installed resulted compressor efficiency of 61.412% with turbine efficiency of 72.076%. Maximum power output of the engine which installed with GT2502-3 turbocharger is equal to 96.823 kW or 129.842 HP at 2200 RPM. Boost pressure value at this point is 2.336 bar with a temperature of 437.356 K. This turbocharger generated high power, but the efficiency of compressor is more bad than GT2052-1.

4.7.3 Turbocharger installed on the engine

On choosing turbocharged on engine must be consideration some criteria, the criteria are :

1. The power output of the engine is the best choice. The best choice of power is the output power of engine is highest than other turbocharger.
2. Based on economic value the engine required less fuel consumption.
3. The engine must have high torque.

So, from criteria the best turbocharger installed on engine is GT2052-3, The value of power is 96,823 Kw, Fuel consumption is 229,023 g/Kwh and torque is 420,269 Nm.

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CHAPTER 5
CONCLUSSION

Based on the simulation results analysis that has been done, obtain some conclusions, among others:

5.1 Summary

1. The influence of variable load of diesel engine 93 KW on turbocharger performance is small. From two turbochargers (GT2052-1 and GT2052-3) the value of efficiency turbine and compressor on the condition constant speed with variables load has a value of nearly the same. The efficiency difference at certain load at constant speed is approximately 0.03%-0.5%.

2. The influence of variable speed of diesel engine 93 KW on turbocharger performance is high. From two turbochargers (GT2052-1 and GT2052-3) the value of efficiency turbine and compressor on the condition variable speeds with constant load has much different. The efficiency difference at certain speeds with constant load is approximately 1%-6%.

5.2 Suggestion

1. Recommendation of this research is changing turbocharger with GT2052-3. Power output of engine with turbocharger GT2052-3 is 96,823 kW and specific fuel oil consumption is 228,032 g/kwh.

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ATTACHEMENT 1

MODEL INPUT

1.1 Input value of load on simulation turbocharger GT2052-1

RPM (rpm)	**120%**	**100%**	**80%**	**60%**	**40%**	**20%**	**0%**
	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)
800	320.96	267.47	213.97	160.48	106.99	53.49	0
1000	353.11	294.26	235.41	176.55	117.70	58.85	0
1200	392.77	327.31	261.85	196.39	130.92	65.46	0
1400	440.01	366.68	293.34	220.01	146.67	73.34	0
1500	463.70	386.42	309.13	231.85	154.57	77.28	0
1600	483.41	402.84	322.27	241.70	161.14	80.57	0
1700	499.20	416.00	332.80	249.60	166.40	83.20	0
1800	508.31	423.59	338.87	254.16	169.44	84.72	0
1900	512.43	427.03	341.62	256.22	170.81	85.41	0
2000	511.63	426.36	341.09	255.82	170.54	85.27	0
2200	487.65	406.37	325.10	243.82	162.55	81.27	0

1.2 Input value of load on simulation turbocharger GT2052-3

RPM (rpm)	120%	100%	80%	60%	40%	20%	0%
	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)	Torque (N.m)
2200	504.32	420.27	336.22	252.16	168.11	84.05	0.00
2000	536.09	446.74	357.39	268.04	178.70	89.35	0.00
1900	543.78	453.15	362.52	271.89	181.26	90.63	0.00
1800	550.01	458.34	366.67	275.00	183.34	91.67	0.00
1700	552.91	460.76	368.61	276.46	184.30	92.15	0.00
1600	552.41	460.34	368.27	276.20	184.14	92.07	0.00
1500	533.77	444.81	355.85	266.89	177.92	88.96	0.00
1400	506.91	422.43	337.94	253.46	168.97	84.49	0.00
1200	444.52	370.43	296.34	222.26	148.17	74.09	0.00
1000	392.93	327.44	261.96	196.47	130.98	65.49	0.00
800	352.48	293.74	234.99	176.24	117.49	58.75	0.00

ATTACHEMENT 2

SIMULATION OUTPUT GT 2052-1

2.1 Output value of load on simulation turbocharger compressor GT2052-1

RPM	120% LOAD	100% LOAD	80% LOAD	60% LOAD	40% LOAD	20% LOAD
	eff	eff	eff	eff	eff	eff
2200	73.92	73.93	73.94	73.94	73.94	73.93
2000	74.21	74.11	74.12	74.08	74.05	74.01
1900	74.67	74.59	74.62	74.59	74.55	74.52
1800	75.09	75.07	75.13	75.12	75.10	75.08
1700	75.27	75.34	75.45	75.48	75.52	75.54
1600	74.85	75.11	75.29	75.46	75.61	75.74
1500	74.11	74.38	74.58	74.76	74.94	75.11
1400	73.38	73.63	73.84	74.02	74.20	74.38
1200	71.70	71.85	72.01	72.15	72.28	72.42
1000	70.04	70.14	70.31	70.45	70.58	70.72
800	68.66	68.71	68.82	68.90	68.99	69.08

2.2 Output value of load on simulation turbocharger turbine GT2052-1

RPM	120% LOAD	100% LOAD	80% LOAD	60% LOAD	40% LOAD	20% LOAD
	eff	eff	eff	eff	eff	eff
2200	71.93	72.02	72.05	72.09	72.14	72.18
2000	71.00	71.14	71.17	71.25	71.31	71.38
1900	70.37	70.54	70.58	70.67	70.75	70.83
1800	69.59	69.79	69.85	69.96	70.06	70.16
1700	68.64	68.87	68.96	69.10	69.22	69.34
1600	67.35	67.63	67.77	67.94	68.10	68.26
1500	65.65	65.99	66.20	66.42	66.63	66.83
1400	63.16	63.60	63.95	64.27	64.58	64.88
1200	55.65	56.20	56.90	57.45	57.98	58.49
1000	46.22	46.73	47.66	48.36	49.05	49.71
800	40.18	40.35	40.82	41.15	41.48	41.83

2.3 Output value of power, SFOC and torque load 100% and 80%

GT 2052-1 (100%)				GT 2052-1 (80%)			
RPM	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**	**RPM**	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**
2200	**93.62**	228.49	406.37	2200	**74.98**	286.80	325.10
2000	89.30	222.17	426.36	2000	71.54	279.07	341.09
1900	84.96	219.95	**427.03**	1900	68.09	276.50	**341.62**
1800	79.85	218.17	423.59	1800	64.02	274.50	338.87
1700	74.06	217.33	416.00	1700	59.42	273.79	332.80
1600	67.50	**216.75**	402.84	1600	54.20	**273.32**	322.27
1500	60.70	216.75	386.42	1500	48.79	273.62	309.13
1400	53.76	217.52	366.68	1400	43.27	274.73	293.34
1200	41.13	221.56	327.31	1200	33.23	279.54	261.85
1000	30.81	227.77	294.26	1000	25.01	286.77	235.41
800	22.41	237.55	267.47	800	18.34	298.87	213.97

2.4 Output value of power, SFOC and torque load 60% and 40%

GT 2052-1 (60%)				GT 2052-1 (40%)			
RPM	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**	**RPM**	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**
2200	**56.41**	383.37	243.82	2200	**37.72**	576.32	162.55
2000	53.86	374.49	255.82	2000	36.04	564.73	170.54
1900	51.29	371.33	**256.22**	1900	34.34	560.35	**170.81**
1800	48.24	368.92	254.16	1800	32.31	557.18	169.44
1700	44.80	368.18	249.60	1700	30.02	556.49	166.40
1600	40.88	**367.57**	241.70	1600	27.41	**555.81**	161.14
1500	36.82	367.90	231.85	1500	24.70	556.49	154.57
1400	32.67	369.49	220.01	1400	21.93	559.06	146.67
1200	25.12	375.49	196.39	1200	16.88	567.41	130.92
1000	18.96	384.56	176.55	1000	12.77	580.17	117.70
800	13.95	400.46	160.48	800	9.43	603.67	106.99

2.5 Output value of power, SFOC and torque load 20%

GT 2052-1 (20%)			
RPM	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**
2200	18.91	1155.12	81.28
2000	18.09	1135.42	85.27
1900	17.24	1127.37	85.41
1800	16.23	1121.92	84.72
1700	15.09	1121.29	83.20
1600	13.78	1120.60	80.57
1500	12.42	1122.32	77.28
1400	11.03	1127.82	73.34
1200	8.51	1143.34	65.46
1000	6.45	1167.09	58.85
800	4.78	1213.41	53.49

2.6 Compressor output

Average Speed	RPM	165365	158134	153932	149007	143623	136837	129566	122103	106678	94168	85240
Average Map Pressure Ratio		2.35	2.33	2.27	2.20	2.12	2.01	1.90	1.79	1.59	1.45	1.37
Average Static Pressure Ratio		2.38	2.36	2.29	2.22	2.13	2.02	1.91	1.79	1.59	1.45	1.37
Average Inlet Pressure	bar	0.95	0.95	0.96	0.96	0.97	0.97	0.98	0.98	0.99	0.99	1.00
Average Outlet Pressure	bar	2.25	2.24	2.19	2.13	2.06	1.97	1.87	1.76	1.57	1.44	1.36
Average Inlet Temperature	K	297.19	297.33	297.48	297.63	297.77	297.91	298.04	298.15	298.31	298.43	298.50
Average Outlet Temperature	K	408.01	406.79	402.42	397.25	391.83	385.39	378.55	370.84	356.83	346.12	339.19
Average Mass Flow Rate	lb/min	18.87	17.87	16.80	15.63	14.40	13.05	11.69	10.34	7.99	6.13	4.63
Average Efficiency	%	73.93	74.11	74.59	75.07	75.34	75.11	74.38	73.63	71.85	70.14	68.71
Average Power	kW	16.01	14.99	13.52	11.94	10.39	8.76	7.22	5.77	3.59	2.24	1.44
Average Reduced Speed	RPM/K^0.5	9566.94	9149.18	8906.49	8621.89	8310.69	7918.30	7497.76	7066.00	6173.49	5449.43	4932.64
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	31.39	29.61	27.73	25.69	23.57	21.27	18.99	16.76	12.89	9.86	7.43
Rack Position		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average Corrected Speed	RPM	165151	157939	153750	148837	143465	136691	129431	121978	106571	94072	85151
Average Corrected Mass Flow	lb/min	19.62	18.50	17.33	16.06	14.73	13.30	11.87	10.47	8.06	6.16	4.65
Average Tip Speed	m/s	451.97	432.21	420.73	407.26	392.55	374.00	354.13	333.73	291.57	257.38	232.98

2.7 Turbine output

Average Speed	RPM	165365	158134	153932	149007	143623	136837	129566	122103	106678	94168	85240
Average Map Pressure Ratio		2.46	2.33	2.25	2.15	2.05	1.94	1.82	1.70	1.50	1.37	1.28
Average Static Pressure Ratio		2.41	2.28	2.20	2.11	2.01	1.90	1.79	1.67	1.48	1.35	1.26
Average Inlet Pressure	bar	2.89	2.68	2.54	2.39	2.25	2.09	1.93	1.78	1.54	1.39	1.29
Average Outlet Pressure	bar	1.20	1.17	1.15	1.13	1.12	1.10	1.08	1.07	1.04	1.03	1.02
Average Inlet Temperature	K	895.60	878.44	868.73	858.47	844.07	832.41	820.07	807.04	776.44	747.82	716.01
Average Outlet Temperature	K	767.86	761.22	758.36	755.74	749.96	747.78	745.66	743.21	731.89	715.95	692.18
Average Mass Flow Rate	lb/min	19.46	17.95	16.92	15.78	14.60	13.28	11.96	10.64	8.31	6.46	4.90
Average Efficiency	%	72.02	71.14	70.54	69.79	68.87	67.63	65.99	63.60	56.20	46.73	40.35
Average Power	kW	22.13	18.71	16.60	14.40	12.18	9.95	7.86	5.98	3.21	1.73	0.94
Average Reduced Speed	RPM/K^0.5	5511	5322	5210	5073	4932	4732	4515	4289	3822	3439	3182
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	18.31	18.11	17.93	17.66	17.30	16.85	16.33	15.65	13.90	11.77	9.42
Wastegate Mass Flow Rate	lb/min	0.16	0.15	0.14	0.13	0.13	0.12	0.11	0.10	0.08	0.00	0.00
Wastegate Diameter	mm	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	0.00	0.00
Average Blade Speed Ratio		0.74	0.74	0.74	0.74	0.75	0.75	0.76	0.78	0.83	0.92	1.05
Average Tip Speed	m/s	474.68	453.92	441.86	427.72	412.27	392.79	371.92	350.49	306.22	270.31	244.68

2.8 Cylinder performance

Engine Speed (end of cycle)	RPM	2200.00	2000.00	1900.00	1800.00	1700.00	1600.00	1500.00	1400.00	1200.00	1000.00	800.00
IMEP720 - Net Indicated Mean Effective Pressure	bar	14.90	15.39	15.37	15.22	14.95	14.48	13.89	13.20	11.83	10.66	9.69
IMEP360 - Gross Indicated Mean Effective Pressure	bar	16.36	16.48	16.29	15.96	15.52	14.90	14.18	13.38	11.84	10.57	9.55
PMEP - Pumping Mean Effective Pressure	bar	-1.46	-1.09	-0.91	-0.74	-0.57	-0.42	-0.29	-0.18	-0.01	0.09	0.15
ISFC - Indicated Specific Fuel Consumption	g/kW-h	199.22	195.73	194.46	193.44	192.92	192.66	192.81	193.50	196.82	202.33	211.16
IMEP Adjusted (Shelby definition)		16.38	16.50	16.31	15.98	15.54	14.92	14.20	13.40	11.86	10.59	9.57
PMEP Adjusted (Shelby definition)	bar	-1.48	-1.11	-0.93	-0.76	-0.60	-0.44	-0.31	-0.20	-0.03	0.07	0.12
Intersection Pumping Integral	bar	-1.24	-0.93	-0.78	-0.62	-0.48	-0.35	-0.23	-0.13	0.02	0.10	0.15
Intersection Gas Exchange Efficiency	fraction	0.92	0.94	0.95	0.96	0.97	0.98	0.98	0.99	1.00	1.01	1.02

2.9 Cylinder Energy

Indicated Efficiency	%	42.03	42.77	43.05	43.28	43.40	43.45	43.42	43.27	42.54	41.38	39.65
Indicated Efficiency - Gross (360)	%	46.15	45.81	45.62	45.39	45.06	44.73	44.33	43.85	42.57	41.04	39.05
Fuel Energy Entering Cylinder, Total	J	3476.45	3527.87	3500.78	3447.27	3377.42	3266.89	3137.34	2991.65	2727.56	2525.34	2397.65
Heat Transfer, Average	kW	11.99	11.39	10.97	10.48	10.12	9.52	8.89	8.26	7.19	6.18	5.31
Heat Transfer, % Total Fuel Energy	%	18.80	19.37	19.78	20.27	21.15	21.86	22.68	23.66	26.36	29.36	33.20

2.10 Cylinder Pressure-Temperature

Pressure, Maximum	bar	151.62	152.79	150.99	148.00	146.99	141.34	134.86	127.78	116.87	107.03	100.29
Crank Angle at Maximum Pressure	deg	7.09	7.06	7.09	7.20	6.92	6.82	6.90	6.85	6.53	6.49	6.29
Pressure, Maximum During Combustion	bar	151.62	152.79	150.99	148.00	146.99	141.34	134.86	127.78	116.87	107.03	100.29
Pressure, Maximum Motoring	bar	95.62	96.00	94.60	92.62	90.57	86.93	82.93	78.58	71.30	65.89	62.51
Pressure Ratio, Combustion (Pmax-comb/Pmax-motor)	fraction	1.59	1.59	1.60	1.60	1.62	1.63	1.63	1.63	1.64	1.62	1.60
Maximum Rate of Pressure Rise	bar/deg	5.52	5.58	5.52	5.42	5.43	5.22	4.99	4.72	4.37	3.99	3.73
Pressure, Cyl. Cycle-End	bar	3.12	3.17	3.12	3.05	2.96	2.84	2.70	2.55	2.30	2.12	2.01
Pressure Change, (Cycle-End to Cycle-End)	fraction	--	--	--	--	--	--	--	--	--	--	--
Temperature, Maximum	K	1942.28	1935.66	1930.65	1924.60	1926.94	1918.23	1908.45	1897.11	1877.82	1844.77	1804.10
Temperature, Maximum Unburned Zone	K	1071.99	1064.36	1059.96	1055.12	1053.46	1047.48	1041.23	1035.24	1026.68	1017.21	1006.99
Temperature, Cyl. Cycle-End	K	421.54	417.99	415.80	413.48	411.00	408.51	406.06	404.01	400.91	399.74	399.01
Temperature, Change (Cycle-End to Cycle-End)	Delta K	0.13	0.20	0.18	0.13	0.08	0.07	0.04	0.01	0.00	0.05	0.11

2.11 Cylinder Combustion

Combustion Start	deg	-13.50	-13.50	-13.50	-13.50	-14.20	-14.20	-14.20	-14.20	-14.80	-14.80	-14.80
Combustion Delay (0-2%)	deg	1.83	1.82	1.82	1.82	1.82	1.82	1.83	1.83	1.84	1.84	1.84
Burned Fuel Fraction		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ignition Delay	deg	4.81	4.80	4.80	4.81	4.10	4.11	4.11	4.11	3.51	3.51	3.51
2% Burned Crank Angle	deg	-11.67	-11.68	-11.68	-11.68	-12.38	-12.38	-12.37	-12.37	-12.96	-12.96	-12.96
50% Burned Crank Angle	deg	6.19	6.03	6.04	6.06	5.39	5.43	5.47	5.51	5.00	5.05	5.09
Burn Duration 10-75%	deg	23.66	23.34	23.37	23.41	23.46	23.54	23.61	23.70	23.87	23.96	24.05
Burn Duration 10-90%	deg	34.01	33.11	33.20	33.31	33.45	33.66	33.87	34.12	34.65	34.91	35.21
Burn Duration 0-50%	deg	19.69	19.53	19.54	19.56	19.59	19.63	19.67	19.71	19.80	19.85	19.89
Burn Duration 0-90%	deg	39.66	38.72	38.82	38.93	39.08	39.30	39.52	39.79	40.34	40.61	40.92

2.12 Cylinder flow

Volumetric Efficiency, Air	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency, Air+Burned Gases	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency, Air+Fuel	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency, All Gases	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency (Manifold), Air	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency (Manifold), Air+Burned Gases	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency (Manifold), Air+Fuel	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency (Manifold), All Gases	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Air Flow Past Intake Valves	mg/cycle	1940.39	1993.85	1976.62	1944.08	1901.06	1835.39	1758.73	1672.84	1517.22	1401.33	1326.78
Trapping Ratio		1.00	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00
EGR Percentage	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel Consumption, Total	mg/cycle	80.85	82.04	81.41	80.17	78.54	75.97	72.96	69.57	63.43	58.73	55.76
Fuel Injected Directly Into Cylinder	mg/cycle	80.85	82.04	81.41	80.17	78.54	75.97	72.96	69.57	63.43	58.73	55.76
Fuel Flow Past Intake Valves	mg/cycle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel Flow Past Intake Valves (Liquid Only)	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.13 Cylinder Composition

Total Mass Trapped at Cyl. Cycle-Start	mg	2034.86	2056.50	2037.51	2003.69	1960.91	1894.65	1817.38	1732.07	1580.03	1467.09	1396.75
Air Mass Trapped at Cyl. Cycle-Start	mg	1940.34	1969.04	1953.92	1924.05	1885.07	1823.37	1751.06	1669.74	1522.34	1409.47	1338.19
Burned Mass Frac at Cyl. Cycle-Start (EGR+Resid)	%	4.57	4.19	4.04	3.91	3.82	3.71	3.60	3.55	3.61	3.88	4.15
Burned Mass Frac at Cyl. Cycle-Start (Lean Burn)	%	2.82	2.58	2.49	2.41	2.35	2.29	2.22	2.19	2.22	2.39	2.56
Fuel Mass Trapped at Cyl. Cycle-Start	mg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vapor Fuel Frac at Cyl. Cycle-Start		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel/Air Ratio Trapped at Cyl. Cycle-Start		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Effective Lambda at Cyl. Cycle-Start		37.49	40.95	42.46	43.83	45.04	46.30	47.74	48.42	47.72	44.35	41.55
Fuel/Air Ratio (Total Fuel/Trapped Air)		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Effective Fuel/Air Ratio at EVO		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Effective Lambda at EVO		1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67
NOx at EVO	ppm	1272.65	1272.65	1272.66	1272.66	1272.65	1272.65	1272.64	1272.64	1272.63	1272.62	1272.61
Total Mass Trapped at Cyl. Cycle-End	mg	2035.51	2082.37	2061.09	2024.40	1977.42	1907.00	1825.04	1734.86	1574.39	1458.55	1385.01
Burned Mass Frac at Cyl. Cycle-End (EGR+Resid)	%	2.88	2.62	2.53	2.44	2.38	2.31	2.24	2.22	2.26	2.43	2.61
Fuel/Air Ratio Trapped at Cyl. Cycle-End		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.14 Engine performance

Engine Speed (cycle average)	RPM	2200.00	2000.00	1900.00	1800.00	1700.00	1600.00	1500.00	1400.00	1200.00	1000.00	800.00
Engine Speed (end of cycle)	RPM	2200.00	2000.00	1900.00	1800.00	1700.00	1600.00	1500.00	1400.00	1200.00	1000.00	800.00
BMEP - Brake Mean Effective Pressure	bar	13.02	13.66	13.68	13.57	13.33	12.91	12.38	11.75	10.49	9.43	8.57
IMEP720 - Net Indicated Mean Effective Pressure	bar	14.91	15.47	15.44	15.28	14.99	14.50	13.90	13.20	11.80	10.61	9.64
IMEP360 -	bar	16.39	16.59	16.38	16.04	15.58	14.94	14.20	13.38	11.81	10.53	9.50
FMEP - Friction Mean Effective Pressure	bar	1.89	1.82	1.77	1.72	1.67	1.60	1.53	1.45	1.31	1.18	1.07
PMEP - Pumping Mean Effective Pressure	bar	-1.48	-1.12	-0.94	-0.76	-0.59	-0.43	-0.30	-0.18	-0.01	0.09	0.15
BSFC - Brake Specific Fuel Consumption	g/kW-h	228.49	222.17	219.95	218.17	217.33	216.75	216.75	217.52	221.56	227.77	237.55
ISFC - Indicated Specific Fuel Consumption	g/kW-h	199.54	196.17	194.86	193.80	193.23	192.92	193.01	193.65	196.86	202.30	211.11
BSAC - Brake Specific Air Consumption	g/kW-h	5483.58	5354.05	5299.04	5254.26	5230.70	5213.55	5210.17	5224.60	5311.99	5456.06	5684.61
ISAC	g/kW-h	4788.76	4727.53	4694.59	4667.26	4650.77	4640.34	4639.49	4651.16	4719.90	4846.12	5051.84
FMEP-PMEP	bar	3.37	2.94	2.71	2.47	2.26	2.03	1.82	1.63	1.32	1.10	0.92
Shaft MEP	bar	13.02	13.66	13.68	13.57	13.33	12.91	12.38	11.75	10.49	9.43	8.57
Attachment MEP	bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crank Pin MEP	bar	14.91	15.47	15.44	15.28	14.99	14.50	13.90	13.20	11.80	10.61	9.64
Average of Maximum Cylinder Pressures	bar	152.14	154.15	152.19	149.04	147.77	141.85	135.17	127.89	116.64	106.62	99.74
Percent Load	%	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
FMEP - Cylinder (if 'EngFrictionDetail' used)	bar	1.89	1.82	1.77	1.72	1.67	1.60	1.53	1.45	1.31	1.18	1.07

2.15 Engine Energy

Indicated Efficiency	**%**	**41.96**	**42.68**	**42.96**	**43.20**	**43.33**	**43.40**	**43.38**	**43.23**	**42.53**	**41.38**	**39.66**
Indicated Efficiency - Gross (360)	%	46.12	45.76	45.57	45.34	45.03	44.70	44.31	43.84	42.57	41.04	39.05
Brake Efficiency	%	36.64	37.68	38.06	38.37	38.52	38.63	38.63	38.49	37.79	36.76	35.24
Fuel Power	kW	255.51	236.96	223.22	208.07	192.24	174.74	157.15	139.67	108.85	83.83	63.58
Fuel Power, Useful Portion	kW	255.51	236.96	223.22	208.07	192.24	174.74	157.15	139.67	108.85	83.83	63.58
In-Cylinder Heat Transfer	kW	48.13	45.91	44.16	42.17	40.67	38.20	35.65	33.06	28.72	24.65	21.14
Total Exhaust Energy Percentage	%	39.21	37.95	37.25	36.53	35.52	34.74	33.94	33.10	31.09	29.21	27.09
Useful Exhaust Energy Percentage	%	39.21	37.95	37.25	36.53	35.52	34.74	33.94	33.10	31.09	29.21	27.09
Exhaust Energy Percentage (MeanV)	%	--	--	--	--	--	--	--	--	--	--	--

2.16 Engine torque power

Brake Torque	N-m	406.37	426.36	427.03	423.59	416.00	402.84	386.42	366.68	327.31	294.26	267.47
Indicated Torque	N-m	465.34	482.86	482.01	476.87	467.88	452.60	433.95	411.88	368.37	331.29	300.97
Friction Torque	N-m	59.01	56.83	55.28	53.54	52.09	49.92	47.63	45.24	40.99	36.93	33.36
Attachment Torque	N-m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crank Pin Torque	N-m	465.34	482.86	482.01	476.87	467.88	452.60	433.95	411.88	368.37	331.29	300.97
Shaft Torque	N-m	406.37	426.36	427.03	423.59	416.00	402.84	386.42	366.68	327.31	294.26	267.47
Brake Power (HP)	HP	125.55	119.75	113.94	107.07	99.31	90.51	81.40	72.09	55.16	41.32	30.05
Brake Power (kW)	kW	93.62	89.30	84.96	79.85	74.06	67.50	60.70	53.76	41.13	30.81	22.41
Indicated Power	kW	107.21	101.13	95.90	89.89	83.29	75.83	68.16	60.39	46.29	34.69	25.21
Friction Power	kW	13.60	11.90	11.00	10.09	9.27	8.36	7.48	6.63	5.15	3.87	2.79
Attachment Power	kW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crank Pin Power	kW	107.21	101.13	95.90	89.89	83.29	75.83	68.16	60.39	46.29	34.69	25.21
Shaft Power	kW	93.62	89.30	84.96	79.85	74.06	67.50	60.70	53.76	41.13	30.81	22.41

2.17 Engine Flow

Volumetric Efficiency, Air	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency, Trapped Air	fraction	1.70	1.73	1.72	1.69	1.66	1.60	1.53	1.46	1.33	1.23	1.16
Volumetric Efficiency, Air+Burned Gas	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency, Air+Fuel Vapor	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency, All Gases	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency (Manifold), Air	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency (Manifold), Trapped Air	fraction	1.70	1.73	1.72	1.69	1.66	1.60	1.53	1.46	1.33	1.23	1.16
Volumetric Efficiency (Manifold), Air+Burned Gas	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Volumetric Efficiency (Manifold), Air+Fuel Vapor	fraction	1.70	1.74	1.73	1.70	1.66	1.60	1.54	1.46	1.33	1.22	1.16
Air Flow	kg/hr	513.38	478.10	450.23	419.53	387.38	351.90	316.25	280.86	218.49	168.13	127.38
Fuel Flow	kg/hr	21.39	19.84	18.69	17.42	16.09	14.63	13.16	11.69	9.11	7.02	5.32
Trapping Ratio		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Air-Fuel Ratio (Inducted Air/Total Fuel)		24.00	24.10	24.09	24.08	24.07	24.05	24.04	24.02	23.98	23.95	23.93
Air-Fuel Ratio (Trapped Air/Total Fuel)		24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
Percent Burned Mass at Cycle Start	%	4.58	4.18	4.03	3.91	3.82	3.72	3.62	3.57	3.65	3.93	4.21

2.18 Engine Emission

Brake Specific NOx	**g/kW-h**	--	--	--	--	--	--	--	--	--	--	--
Brake Specific CO	g/kW-h	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Brake Specific CO2	g/kW-h	729.82	707.44	700.56	695.11	692.75	691.27	691.70	694.64	708.47	728.80	760.58
Brake Specific Hydrocarbon	g/kW-h	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Brake Specific Soot	g/kW-h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx Concentration (ppm)	ppm	--	--	--	--	--	--	--	--	--	--	--
CO Concentration (ppm)	ppm	2.17	2.16	2.17	2.20	2.24	2.29	2.35	2.42	2.58	2.72	2.84
CO2 Concentration (ppm)	ppm	84212.20	83916.80	83937.10	83961.40	84006.50	84046.80	84094.30	84149.20	84181.90	84173.80	84163.80
Hydrocarbon Concentration (ppm)	ppm	0.61	0.61	0.60	0.60	0.61	0.60	0.61	0.61	0.61	0.60	0.60
Soot Concentration (Exhaust @ STP)	g/m^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ATTACHEMENT 3

SIMULATION OUTPUT GT2052-3

3.1 Output value of load on simulation turbocharger compressor GT2052-3

RPM	120% LOAD	100% LOAD	80% LOAD	60% LOAD	40% LOAD	20% LOAD
	eff	eff	eff	eff	eff	eff
2200	61.84	61.41	61.07	60.72	60.38	60.02
2000	65.79	65.38	65.06	64.71	64.39	64.06
1900	67.69	67.40	67.15	66.88	66.62	66.36
1800	69.29	69.11	68.98	68.80	68.61	68.41
1700	70.21	70.18	70.16	70.12	70.06	69.98
1600	70.56	70.58	70.58	70.58	70.58	70.57
1500	70.58	70.73	70.83	70.89	70.93	70.95
1400	70.20	70.41	70.61	70.78	70.92	71.04
1200	69.66	69.86	70.13	70.32	70.50	70.66
1000	67.89	67.99	68.23	68.38	68.54	68.69
800	66.42	66.48	66.74	66.89	67.04	67.20

3.2 Output value of load on simulation turbocharger turbine GT2052-3

RPM	120% LOAD	100% LOAD	80% LOAD	60% LOAD	40% LOAD	20% LOAD
	eff	eff	eff	eff	eff	eff
2200	72.03	72.08	72.10	72.13	72.16	72.18
2000	71.21	71.27	71.32	71.37	71.43	71.48
1900	70.65	70.72	70.78	70.83	70.89	70.94
1800	69.94	70.04	70.12	70.21	70.29	70.37
1700	69.03	69.16	69.27	69.39	69.49	69.60
1600	67.95	68.18	68.34	68.47	68.60	68.72
1500	66.38	66.70	67.00	67.25	67.48	67.69
1400	64.04	64.45	64.91	65.27	65.59	65.91
1200	56.30	56.81	57.86	58.52	59.15	59.74
1000	46.62	46.92	47.99	48.68	49.41	50.14
800	40.95	41.06	41.65	42.00	42.36	42.73

3.3 Output value of power, SFOC and torque load 100% and 80%

GT 2052-3 (100%)				GT 2052-3 (80%)			
RPM	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**	**RPM**	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**
2200	96.82	228.02	420.27	2200	77.63	285.26	336.22
2000	93.56	220.60	446.74	2000	75.09	275.75	357.39
1900	90.16	217.47	453.15	1900	72.40	271.84	362.52
1800	86.39	215.01	458.34	1800	69.42	268.77	366.67
1700	82.03	213.88	460.76	1700	65.95	267.35	368.61
1600	77.13	213.17	460.34	1600	62.07	267.60	368.27
1500	69.87	212.81	444.81	1500	56.31	269.37	355.85
1400	61.93	213.30	422.43	1400	49.99	270.44	337.94
1200	46.55	217.20	370.43	1200	37.75	275.86	296.35
1000	34.29	223.27	327.44	1000	27.99	282.46	261.96
800	24.61	232.96	293.74	800	20.30	293.81	234.99

3.4 Output value of power, SFOC and torque load 60% and 40%

GT 2052-3 (60%)				GT 2052-3 (40%)			
RPM	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**	**RPM**	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**
2200	**58.40**	380.31	252.16	2200	**39.05**	570.20	168.11
2000	56.54	367.66	268.04	2000	37.84	551.49	178.70
1900	54.54	362.46	**271.89**	1900	36.52	543.68	**181.26**
1800	52.32	358.36	275.00	1800	35.06	537.53	183.34
1700	49.75	356.47	276.46	1700	33.35	534.71	184.30
1600	46.85	**356.80**	276.20	1600	31.43	**535.20**	184.14
1500	42.53	362.82	266.89	1500	28.55	548.70	177.92
1400	37.79	364.26	253.46	1400	25.38	551.24	168.97
1200	28.57	371.21	222.26	1200	19.22	562.05	148.17
1000	21.23	379.27	196.47	1000	14.31	572.94	130.98
800	15.47	393.95	176.24	800	10.47	594.27	117.49

3.5 Output value of power, SFOC and torque load 20%

GT 2052-3 (20%)			
RPM	**POWER (kW)**	**SFOC (g/kwh)**	**TORQUE (Nm)**
2200	**19.59**	1139.66	84.05
2000	18.99	1102.98	89.35
1900	18.34	1087.37	**90.63**
1800	17.61	1075.06	91.67
1700	16.77	1069.41	92.15
1600	15.81	**1070.39**	92.07
1500	14.38	1105.79	88.96
1400	12.79	1112.72	84.49
1200	9.70	1134.72	74.09
1000	7.24	1154.14	65.49
800	5.31	1195.34	58.75

3.6 Compressor Output

Average Speed	RPM	178662	172532	168254	163417	158095	152204	145363	137433	119800	104636	94225
Average Map Pressure Ratio		2.45	2.48	2.47	2.43	2.37	2.28	2.16	2.03	1.76	1.58	1.47
Average Static Pressure Ratio		2.48	2.51	2.50	2.45	2.39	2.30	2.18	2.04	1.77	1.58	1.47
Average Inlet Pressure	bar	0.94	0.95	0.95	0.96	0.96	0.97	0.97	0.98	0.99	0.99	1.00
Average Outlet Pressure	bar	2.34	2.38	2.37	2.35	2.30	2.22	2.12	1.99	1.75	1.57	1.46
Average Inlet Temperature	K	297.08	297.23	297.34	297.47	297.61	297.76	297.91	298.05	298.27	298.40	298.49
Average Outlet Temperature	K	437.36	431.31	426.54	421.06	415.31	409.08	401.18	392.15	373.13	359.53	350.53
Average Mass Flow Rate	lb/min	19.60	18.66	17.91	16.96	15.82	14.54	13.10	11.60	8.81	6.63	4.95
Average Efficiency	%	61.41	65.38	67.40	69.11	70.18	70.58	70.73	70.41	69.86	67.99	66.48
Average Power	kW	21.13	19.22	17.78	16.10	14.30	12.43	10.39	8.39	5.06	3.11	1.98
Average Reduced Speed	RPM/K^0.5	10336	9982	9735	9455	9148	8807	8412	7953	6933	6055	5453
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	32.68	30.99	29.67	27.99	26.01	23.80	21.37	18.85	14.23	10.67	7.96
Rack Position		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average Corrected Speed	RPM	178426	172313	168046	163222	157913	152035	145207	137290	119679	104530	94127
Average Corrected Mass Flow	lb/min	20.43	19.37	18.54	17.49	16.25	14.87	13.35	11.78	8.89	6.67	4.98
Average Tip Speed	m/s	488.32	471.56	459.87	446.65	432.10	416.00	397.30	375.63	327.44	285.99	257.53

3.7 Turbine output

Average Speed	RPM	178662	172532	168254	163417	158095	152204	145363	137433	119800	104636	94225
Average Map Pressure Ratio		2.54	2.45	2.38	2.30	2.20	2.10	1.98	1.85	1.60	1.43	1.32
Average Static Pressure Ratio		2.48	2.40	2.33	2.25	2.16	2.06	1.95	1.82	1.58	1.42	1.31
Average Inlet Pressure	bar	3.01	2.85	2.74	2.61	2.46	2.32	2.15	1.97	1.66	1.47	1.34
Average Outlet Pressure	bar	1.21	1.19	1.17	1.16	1.14	1.12	1.10	1.08	1.05	1.04	1.03
Average Inlet Temperature	K	898.04	873.06	857.90	847.94	839.75	837.54	825.43	812.36	780.73	750.90	718.39
Average Outlet Temperature	K	765.81	749.87	740.93	737.52	736.63	741.67	739.41	737.61	728.60	714.24	691.19
Average Mass Flow Rate	lb/min	20.07	19.08	18.33	17.37	16.24	14.96	13.54	12.04	9.23	7.07	5.29
Average Efficiency	%	72.08	71.27	70.72	70.04	69.16	68.18	66.70	64.45	56.81	46.92	41.06
Average Power	kW	23.60	20.85	18.97	16.97	14.82	12.71	10.31	7.95	4.21	2.20	1.18
Average Reduced Speed	RPM/K^0.5	5946.72	5824.39	5730.07	5598.09	5442.40	5246.86	5048.16	4811.59	4279.72	3812.78	3511.15
Average Reduced Mass Flow	(lbs/min)-R^0.5/psi	18.17	18.01	17.89	17.74	17.50	17.18	16.71	16.11	14.42	12.29	9.83
Wastegate Mass Flow Rate	lb/min	0.17	0.16	0.15	0.15	0.14	0.13	0.12	0.11	0.09	0.00	0.00
Wastegate Diameter	mm	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	0.00	0.00
Rack Position		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average Blade Speed Ratio		0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.81	0.86	0.94	1.08
Average Tip Speed	m/s	512.85	495.25	482.97	469.09	453.81	436.90	417.26	394.50	343.89	300.36	270.47

3.8 Cylinder performance

Engine Speed (end of cycle)	RPM	2200	2000	1900	1800	1700	1600	1500	1400	1200	1000	800
IMEP720 - Net Indicated Mean Effective Pressure	bar	15.34	16.19	16.36	16.48	16.52	16.43	15.88	15.09	13.29	11.79	10.59
IMEP360 - Gross Indicated Mean Effective Pressure	bar	16.86	17.37	17.35	17.28	17.13	16.87	16.16	15.24	13.25	11.64	10.38
PMEP - Pumping Mean Effective Pressure	bar	-1.52	-1.18	-0.99	-0.80	-0.61	-0.44	-0.29	-0.15	0.04	0.15	0.21
ISFC - Indicated Specific Fuel Consumption	g/kW-h	199.26	195.06	193.05	191.62	191.13	191.09	190.99	191.46	194.55	199.80	208.43
IMEP Adjusted (Shelby definition)		16.88	17.39	17.37	17.30	17.16	16.90	16.19	15.26	13.27	11.66	10.40
PMEP Adjusted (Shelby definition)	bar	-1.54	-1.20	-1.01	-0.82	-0.64	-0.47	-0.31	-0.18	0.02	0.13	0.19
Intersection Pumping Integral	bar	-1.29	-1.01	-0.84	-0.67	-0.51	-0.36	-0.22	-0.10	0.07	0.17	0.22
Intersection Gas Exchange Efficiency	fraction	0.92	0.94	0.95	0.96	0.97	0.98	0.99	0.99	1.01	1.01	1.02

3.9 Cylinder Energy

Indicated Efficiency	%	42.02	42.92	43.37	43.69	43.80	43.81	43.84	43.73	43.03	41.90	40.17
Indicated Efficiency - Gross (360)	%	46.19	46.05	45.99	45.81	45.43	44.99	44.63	44.17	42.90	41.36	39.36
Fuel Energy Entering Cylinder, Total	J	3579.94	3698.00	3698.00	3698.00	3698.00	3677.36	3551.25	3383.09	3028.67	2758.92	2585.04
Fuel Energy (LHV) Multiplier		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Heat Transfer, Average	kW	12.28	11.80	11.38	11.00	10.82	10.44	9.79	9.08	7.79	6.61	5.62
Heat Transfer, % Total Fuel Energy	%	18.72	19.14	19.44	19.83	20.66	21.30	22.07	23.00	25.71	28.73	32.60
Exhaust Energy Percent (MeanV)	%	--	--	--	--	--	--	--	--	--	--	--

3.10 Cylinder pressure - temperature

Pressure, Maximum	bar	156.54	162.40	163.27	162.74	163.78	160.07	153.59	145.30	130.27	117.19	108.27
Crank Angle at Maximum Pressure	deg	7.12	7.17	7.09	6.99	6.92	6.96	6.84	6.90	6.65	6.45	6.34
Pressure, Maximum During Combustion	bar	156.54	162.40	163.27	162.74	163.78	160.07	153.59	145.30	130.27	117.19	108.27
Pressure, Maximum Motoring	bar	98.78	102.41	103.06	102.47	101.24	98.34	94.29	89.16	79.22	71.84	67.14
Pressure Ratio, Combustion (Pmax-comb/Pmax-motor)	fraction	1.58	1.59	1.58	1.59	1.62	1.63	1.63	1.63	1.64	1.63	1.61
Maximum Rate of Pressure Rise	bar/deg	5.70	5.93	5.96	5.94	6.05	5.93	5.69	5.39	4.88	4.38	4.04
Pressure, Cyl. Cycle-End	bar	3.24	3.34	3.36	3.34	3.28	3.18	3.04	2.87	2.54	2.30	2.15
Pressure Change, (Cycle-End to Cycle-End)	fraction	--	--	--	--	--	--	--	--	--	--	--
Temperature, Maximum	K	1944.27	1930.25	1918.61	1913.27	1923.57	1926.68	1917.63	1906.70	1887.07	1853.50	1812.27
Temperature, Maximum Unburned Zone	K	1074.43	1067.35	1063.05	1058.71	1057.59	1052.17	1045.89	1039.39	1029.31	1018.36	1007.29
Temperature, Cyl. Cycle-End	K	422.42	418.49	416.21	414.01	411.82	409.69	407.09	404.72	400.91	399.02	398.01
Temperature, Change (Cycle-End to Cycle-End)	Delta K	0.06	0.05	0.05	0.05	0.04	0.02	0.01	0.03	0.04	0.00	0.11

3.11 Cylinder Combustion

Combustion Start	deg	-13.50	-13.50	-13.50	-13.50	-14.20	-14.20	-14.20	-14.20	-14.80	-14.80	-14.80
Combustion Delay (0-2%)	deg	1.82	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.84	1.84	1.85
Burned Fuel Fraction		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ignition Delay	deg	4.81	4.81	4.80	4.81	4.10	4.11	4.11	4.11	3.51	3.51	3.51
2% Burned Crank Angle	deg	-11.68	-11.67	-11.67	-11.67	-12.37	-12.37	-12.37	-12.37	-12.96	-12.96	-12.95
50% Burned Crank Angle	deg	6.17	6.19	6.14	6.13	5.47	5.52	5.55	5.59	5.07	5.13	5.15
Burn Duration 10-75%	deg	23.61	23.65	23.55	23.54	23.62	23.70	23.77	23.84	24.01	24.12	24.17
Burn Duration 10-90%	deg	33.88	34.03	33.80	33.78	33.97	34.14	34.33	34.55	35.06	35.44	35.57
Burn Duration 0-50%	deg	19.67	19.69	19.64	19.63	19.67	19.72	19.75	19.79	19.87	19.93	19.95
Burn Duration 0-90%	deg	39.53	39.69	39.45	39.43	39.63	39.80	40.01	40.23	40.77	41.16	41.30

3.12 Cylinder flow

Volumetric Efficiency, Air	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency, Air+Burned Gases	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency, Air+Fuel	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency, All Gases	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), Air	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), Air+Burned Gases	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), Air+Fuel	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), All Gases	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Air Flow Past Intake Valves	mg/cycle	2006.15	2099.49	2123.38	2124.48	2101.76	2055.56	1981.49	1883.87	1678.57	1523.51	1425.87
Trapping Ratio		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EGR Percentage	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel Consumption, Total	mg/cycle	83.25	86.00	86.00	86.00	86.00	85.52	82.59	78.68	70.43	64.16	60.12
Fuel Injected Directly Into Cylinder	mg/cycle	83.25	86.00	86.00	86.00	86.00	85.52	82.59	78.68	70.43	64.16	60.12
Fuel Flow Past Intake Valves	mg/cycle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel Flow Past Intake Valves (Liquid Only)	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.13 Cylinder Comparation

Total Mass Trapped at Cyl. Cycle-Start	**mg**	**2096.35**	**2185.43**	**2207.42**	**2205.68**	**2179.88**	**2129.92**	**2054.04**	**1954.88**	**1750.02**	**1597.77**	**1500.96**
Air Mass Trapped at Cyl. Cycle-Start	mg	1998.10	2091.22	2115.84	2117.94	2096.75	2052.47	1982.09	1888.23	1690.41	1539.85	1442.79
Burned Mass Frac at Cyl. Cycle-Start (EGR+Resid)	%	4.61	4.24	4.09	3.92	3.76	3.59	3.46	3.36	3.37	3.59	3.83
Burned Mass Frac at Cyl. Cycle-Start (Lean Burn)	%	2.84	2.59	2.47	2.36	2.29	2.21	2.13	2.07	2.08	2.21	2.36
Fuel Mass Trapped at Cyl. Cycle-Start	mg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vapor Fuel Frac at Cyl. Cycle-Start		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel/Air Ratio Trapped at Cyl. Cycle-Start		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Effective Lambda at Cyl. Cycle-Start		37.16	40.74	42.83	44.74	46.26	47.91	49.74	51.10	51.15	48.06	44.95
Fuel/Air Ratio (Total Fuel/Trapped Air)		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Effective Fuel/Air Ratio at EVO		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Effective Lambda at EVO		1.67	1.70	1.72	1.72	1.70	1.67	1.67	1.67	1.67	1.67	1.67
NOx at EVO	ppm	1272.65	1285.35	1296.65	1297.62	1288.00	1272.65	1272.66	1272.65	1272.64	1272.63	1272.62
Total Mass Trapped at Cyl. Cycle-End	mg	2104.79	2194.27	2215.44	2212.61	2185.15	2132.98	2053.00	1949.76	1737.22	1580.66	1483.36
Burned Mass Frac at Cyl. Cycle-End (EGR+Resid)	%	2.89	2.63	2.50	2.40	2.32	2.24	2.16	2.10	2.11	2.26	2.42
Fuel/Air Ratio Trapped at Cyl. Cycle-End		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.14 Engine Performance

Engine Speed (cycle average)	RPM	2200.00	2000.00	1900.00	1800.00	1700.00	1600.00	1500.00	1400.00	1200.00	1000.00	800.00
Engine Speed (end of cycle)	RPM	2200.00	2000.00	1900.00	1800.00	1700.00	1600.00	1500.00	1400.00	1200.00	1000.00	800.00
BMEP - Brake Mean Effective Pressure	bar	13.46	14.31	14.52	14.68	14.76	14.75	14.25	13.53	11.87	10.49	9.41
IMEP720 - Net Indicated Mean Effective Pressure	bar	15.38	16.18	16.35	16.47	16.51	16.44	15.87	15.07	13.25	11.73	10.53
IMEP360 - Gross Indicated Mean Effective Pressure	bar	16.93	17.38	17.35	17.28	17.14	16.89	16.17	15.23	13.21	11.58	10.31
FMEP - Friction Mean Effective Pressure	bar	1.92	1.87	1.83	1.79	1.75	1.69	1.62	1.54	1.38	1.23	1.11
PMEP - Pumping Mean Effective Pressure	bar	-1.55	-1.20	-1.01	-0.81	-0.63	-0.45	-0.30	-0.16	0.04	0.15	0.22
BSFC - Brake Specific Fuel Consumption	g/kW-h	228.02	220.60	217.47	215.01	213.88	213.17	212.81	213.30	217.20	223.27	232.96
ISFC - Indicated Specific Fuel Consumption	g/kW-h	199.65	195.19	193.16	191.71	191.22	191.25	191.10	191.53	194.51	199.68	208.28
BSAC - Brake Specific Air Consumption	g/kW-h	5479.61	5398.56	5380.48	5320.48	5232.32	5118.91	5107.46	5116.13	5201.55	5339.71	5568.84
ISAC - Indicated Specific Air Consumption	g/kW-h	4797.73	4776.69	4778.95	4743.96	4677.96	4592.49	4586.48	4593.94	4658.08	4775.44	4979.04
FMEP-PMEP	bar	3.46	3.07	2.84	2.60	2.38	2.15	1.91	1.70	1.34	1.08	0.89
Shaft MEP	bar	13.46	14.31	14.52	14.68	14.76	14.75	14.25	13.53	11.87	10.49	9.41
Attachment MEP	bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crank Pin MEP	bar	15.38	16.18	16.35	16.47	16.51	16.44	15.87	15.07	13.25	11.73	10.53
Average of Maximum Cylinder Pressures	bar	157.45	163.23	163.99	163.34	164.21	160.36	153.67	145.25	129.89	116.54	107.56
FMEP - Cylinder (if 'EngFrictionDetail' used)	bar	1.92	1.87	1.83	1.79	1.75	1.69	1.62	1.54	1.38	1.23	1.11
FMEP - Crankshaft (if 'EngFrictionDetail' used)	bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FMEP - Valvetrain (if 'EngFrictionDetail used)	bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.15 Engine Energy

Indicated Efficiency	%	41.93	42.89	43.34	43.67	43.78	43.78	43.81	43.71	43.04	41.93	40.20
Indicated Efficiency - Gross (360)	%	46.15	46.08	46.02	45.83	45.44	44.98	44.63	44.17	42.91	41.38	39.37
Brake Efficiency	%	36.72	37.95	38.50	38.94	39.14	39.27	39.34	39.25	38.54	37.50	35.94
Fuel Power	kW	263.70	246.53	234.21	221.88	209.55	196.39	177.60	157.78	120.77	91.45	68.47
Fuel Power, Useful Portion	kW	263.70	246.53	234.21	221.88	209.55	196.39	177.60	157.78	120.77	91.45	68.47
In-Cylinder Heat Transfer	kW	49.42	47.24	45.57	44.05	43.32	41.84	39.21	36.32	31.08	26.31	22.36
Total Exhaust Energy Percentage	%	39.32	37.94	37.20	36.48	35.55	34.92	34.11	33.27	31.22	29.30	27.15
Useful Exhaust Energy Percentage	%	39.32	37.94	37.20	36.48	35.55	34.92	34.11	33.27	31.22	29.30	27.15
Exhaust Energy Percentage (MeanV)	%	--	--	--	--	--	--	--	--	--	--	--

3.16 Engine Torque- power

Brake Torque	N-m	420.27	446.74	453.15	458.34	460.76	460.34	444.81	422.43	370.43	327.44	293.74
Indicated Torque	N-m	480.00	504.90	510.19	514.04	515.36	513.11	495.34	470.44	413.65	366.14	328.53
Friction Torque	N-m	59.84	58.25	57.12	55.77	54.65	52.81	50.51	47.95	43.06	38.48	34.58
Attachment Torque	N-m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crank Pin Torque	N-m	480.00	504.90	510.19	514.04	515.36	513.11	495.34	470.44	413.65	366.14	328.53
Shaft Torque	N-m	420.27	446.74	453.15	458.34	460.76	460.34	444.81	422.43	370.43	327.44	293.74
Brake Power (HP)	HP	129.84	125.47	120.91	115.86	110.00	103.43	93.70	83.05	62.42	45.98	33.00
Brake Power (kW)	kW	96.82	93.56	90.16	86.39	82.03	77.13	69.87	61.93	46.55	34.29	24.61
Indicated Power	kW	110.58	105.75	101.51	96.89	91.75	85.97	77.81	68.97	51.98	38.34	27.52
Friction Power	kW	13.79	12.20	11.36	10.51	9.73	8.85	7.93	7.03	5.41	4.03	2.90
Attachment Power	kW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crank Pin Power	kW	110.58	105.75	101.51	96.89	91.75	85.97	77.81	68.97	51.98	38.34	27.52
Shaft Power	kW	96.82	93.56	90.16	86.39	82.03	77.13	69.87	61.93	46.55	34.29	24.61

3.17 Engine Flow

Volumetric Efficiency, Air	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency, Trapped Air	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.34	1.25
Volumetric Efficiency, Air+Burned Gas	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency, Air+Fuel Vapor	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency, All Gases	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), Air	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), Trapped Air	fraction	1.75	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.34	1.25
Volumetric Efficiency (Manifold), Air+Burned Gas	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), Air+Fuel Vapor	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Volumetric Efficiency (Manifold), All Gases	fraction	1.76	1.84	1.86	1.86	1.84	1.80	1.73	1.65	1.47	1.33	1.25
Air Flow	kg/hr	530.55	505.11	485.12	459.66	429.19	394.83	356.86	316.85	242.13	183.10	137.04
Fuel Flow	kg/hr	22.08	20.64	19.61	18.58	17.54	16.44	14.87	13.21	10.11	7.66	5.73
EGR Percentage (normalized by Air+Burned Gas)	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trapping Ratio		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Air-Fuel Ratio (Inducted Air/Total Fuel)		24.03	24.47	24.74	24.75	24.46	24.01	24.00	23.99	23.95	23.92	23.91
Air-Fuel Ratio (Trapped Air/Total Fuel)		24.00	24.44	24.71	24.72	24.44	24.00	24.00	24.00	24.00	24.00	24.00
Percent Burned Mass at Cycle Start	%	4.61	4.25	4.09	3.92	3.77	3.60	3.47	3.39	3.41	3.64	3.90

3.18 Engine Combustion

Brake Specific NOx	**g/kW-h**	--	--	--	--	--	--	--	--	--	--	--
Brake Specific CO	g/kW-h	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Brake Specific CO2	g/kW-h	727.68	704.82	694.84	686.97	683.34	680.77	679.95	681.89	695.24	715.31	746.53
Brake Specific Hydrocarbon	g/kW-h	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Brake Specific Soot	g/kW-h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx Concentration (ppm)	ppm	--	--	--	--	--	--	--	--	--	--	--
CO Concentration (ppm)	ppm	2.14	2.05	2.01	2.02	2.07	2.16	2.20	2.27	2.44	2.60	2.73
Hydrocarbon Concentration (ppm)	ppm	0.60	0.60	0.59	0.59	0.59	0.61	0.61	0.61	0.61	0.61	0.60
Soot Concentration (Exhaust @ STP)	g/m^3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

AUTHOR’S BIOGRAPHY

The author was born in Baubau, south Sulawesi, April 28, 1994, is the first child of four brother and one sister. Author of formal education is in TK. Bayangkari Kota Baubau, SD Negeri 3 Baubau, SMP Negeri 1 Baubau, SMA Negeri 1 Baubau. Graduated from the State SMA Negeri 1 Baubau, the author continue to Double Bachelor Degree program with a major in Marine Engineering FTK - ITS through the Double Degree in 2012. Registered with the Student Registration Number 4212101021. The Department of Marine Engineering author takes a field of study Marine Power Plant (MPP). Among them are Members of Marine Engineering Student Association ITS (HIMASISKAL ITS).